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Applicability of the Meyers Process for Chemical Desulfurization of Coal
Survey of Thirty-Five Coals

TRW Systems Group

Prepared For
Industrial Environmental Research Lab.

September 1975

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The report details experimentation on the application of chemical cleaning (desulfurization) technology to a variety of U.S. coals. Run-of-mine coal samples were collected from 35 U.S. coal mines in 13 states. Each sample was treated separately by the Meyers process for selective chemical removal of coal-pyrite and by float-sink procedures for physical coal cleaning. Raw and chemically treated coals were examined for sulfur distribution as well as for selective trace element distribution and other process characterizing features, such as heat content and ash changes and leaching agent residuals. Comparisons of physical and chemical impacts on sulfur reductions are discussed.

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by

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ABSTRACT

Run-of-mine coal samples were collected from each of 35 U.S. mines located in 13 states from New Mexico and Montana to West Virginia and Pennsylvania. Each coal was treated separately by the Meyers Process (ferric sulfate extraction) and float-sink fractionation (physical cleaning). The Meyers Process removed 90-99% of the pyritic sulfur (23-80% of the total sulfur) from all of the coals which contained sufficient pyritic sulfur for accurate sulfur determination (i.e., greater than 0.25% w/w). Fourteen of the coals were reduced to less than 1% total sulfur by the Meyers Process, while five of the coals were reduced to less than 1% total sulfur by physical cleaning (1.90 float material, 14 mesh x 0). With the exception of two mines, the Meyers Process removed significant to very large increments of sulfur above that quantity which was separable by physical cleaning. Significant amounts of Ag, As, Cd, Cr, Cu, Mn, Ni, Sb, and Zn were removed along with the pyrite by the Meyers Process, while float-sink procedures removed significant amounts of Ag, As, Cr, Cu, F, Li, Mn, and Zn.

This report was submitted in fulfillment of Contract Modification No. 1 of Contract 68-02-0647 under the sponsorship of the Office of Research and Development, Environmental Protection Agency.

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1.0 CONCLUSIONS

1. Only one of the thirty-five run-of-mine (ROM) coals investigated in this survey met the Clean Air Act sulfur oxide emission standard of 0.6 lbs* of sulfur/10^6 btu for new stationary combustion sources.

2. The process for chemical removal of pyritic sulfur from coal (Meyers Process) was demonstrated to remove (operating at $100^{o}C$):

a) 90 to 99% of the pyritic sulfur (23 to 80% of the total sulfur) from the twenty-three Appalachian Basin coals experimentally investigated in the survey program. An additional coal obtained from the Walker Mine, contained insufficient pyritic sulfur, 0.07% w/w, for measurable evaluation in this program.

b) 91 to 99% of the pyritic sulfur (43 to 57% of the total sulfur) from the six Eastern Interior Basin coals investigated.

c) 98% of the pyritic sulfur (64% of the total sulfur) from the single Western Interior Basin coal investigated.

d) 59 to 89% of the pyritic sulfur from the four Western coals investigated. Of these four samples, only coal from the Colstrip and Navajo Mines contained sufficient pyritic sulfur to give reasonably accurate results.

e) significant amounts of Ag, As, Cd, Cr, Cu, Mn, Ni, Sb, and Zn.

3. Seven potentially hazardous trace elements — Ag, Be, Cd, Hg, Sb, Se and Sn — were generally present in the coals studied in amounts that may be only of minimal environmental significance (<5 ppm) for effluents from coal combustion facilities.

4. The Meyers Process reduced the total sulfur content of 14 coals under investigation to below 1.0% (eight of these were reduced to 0.75% or less).

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*EPA policy is to express all data in Agency documents in metric units. Because implementing this practice will result in undue cost, NERC/RTP is providing conversion factors for the particular non-metric units used in this document. These factors are located on page 83.

5. The major factor determining the ultimate amount of pyrite removal in ROM Eastern coals was the top size of the coal. While 40-50% of the coals gave 90-99% removal with a 149μ (100 mesh) top size, the remaining coals had to be reduced to 105μ (150 mesh) top size and some to 74μ (200 mesh) top size. The size reduction also resulted in a substantial increase in the rate of pyrite removal so that in most cases, the reaction time could be reduced from 23 hours to 13 hours or less.

6. The rate of pyrite removal was measured as a function of time for twenty coals, and it was found that the median percentages of removal were as follows: 68% in 1 hour, 78% in 3 hours, 87% in 6 hours, 90% in 13 hours, and 94% in 23 hours.

7. Most coals showed an increase in heat content after Meyers Process treatment. For the Appalachian and some of the Eastern Interior Basin coals, this heat content rise amounted to 1-11% of the initial heating value. When calculated on a dry mineral matter free basis, which takes into account the ash reduction due to pyrite removal, an average heat content loss of 7 ±2.1% was found for Western coals, Interior Basin coals lost 4 ±1.5%, and Appalachian coals lost an insignificant 1 ±1.2%.

8. Sulfate retention, although variable, was least for Appalachian coals, averaging 0.09%; intermediate for Interior Basin coals, averaging 0.26%; and high for Western coals. Reduction of leaching time to 12-14 hours for the Western and Interior Basin coals reduced retention significantly.

9. Ash removal, in addition to that accounted for by pyrite removal, was observed in varying degrees for all coals and increased with increasing ash content in the coal. Excess ash removal was minimal for Appalachian coals, intermediate for Interior Basin coals, and greatest for Western coals.

10. A single-stage toluene extraction for elemental sulfur was found to be inadequate and in some cases resulted in apparent increases in organic sulfur.

11. A vaporization technique at 375°C has been shown to be effective in removing residual sulfur in those cases where a single stage toluene extraction has been found to be inadequate.

12. Filtration rates were proportional to the amount of ash present in the coals. High ash coals filtered significantly slower than low ash coals.

13. Float-sink testing showed that conventional coal cleaning could reduce the sulfur content of only two of the coals tested to the level obtainable by the Meyers Process.

14. Varying amounts of 18 selected trace metals (see Section 4.5) were removed by the Meyers Process and by conventional coal cleaning. The Meyers Process removed significant amounts (>50%) of Ag, As, Cd, Cr, Mn, Ni, Sb and Zn, while float-sink procedures removed substantial amounts (>50%) of Ag, As, Cr, F, Li, Mn, and Zn in the majority of the coals. Substantial differences were found for Mn and Pb for which the removal was found to be significantly higher using the Meyers Process, and for F and Li, where float-sink methods removed significantly greater amounts.

15. An atomic absorption method for the analysis of pyritic sulfur was developed which has precision and accuracy equivalent to the ASTM procedure.

2.0 RECOMMENDATIONS

1. The Meyers Process should continue to be tested on additional coals from all parts of the U.S. in order to further define the applicability of the process for meeting legislated sulfur oxide pollution control standards.

2. Future studies should include rate studies concerned with the removal of pyritic sulfur from various coal size and density fractions which are typical of the output of coal preparation units, for the purpose of establishing optimum combinations of the Meyers Process with current coal handling and treatment practices.

3. In order to further define process economics on a wide variety of coals, the raw rate data obtained and partially treated in Section 4.3.3 should be reduced to kinetic rate expressions and evaluated in greater detail.

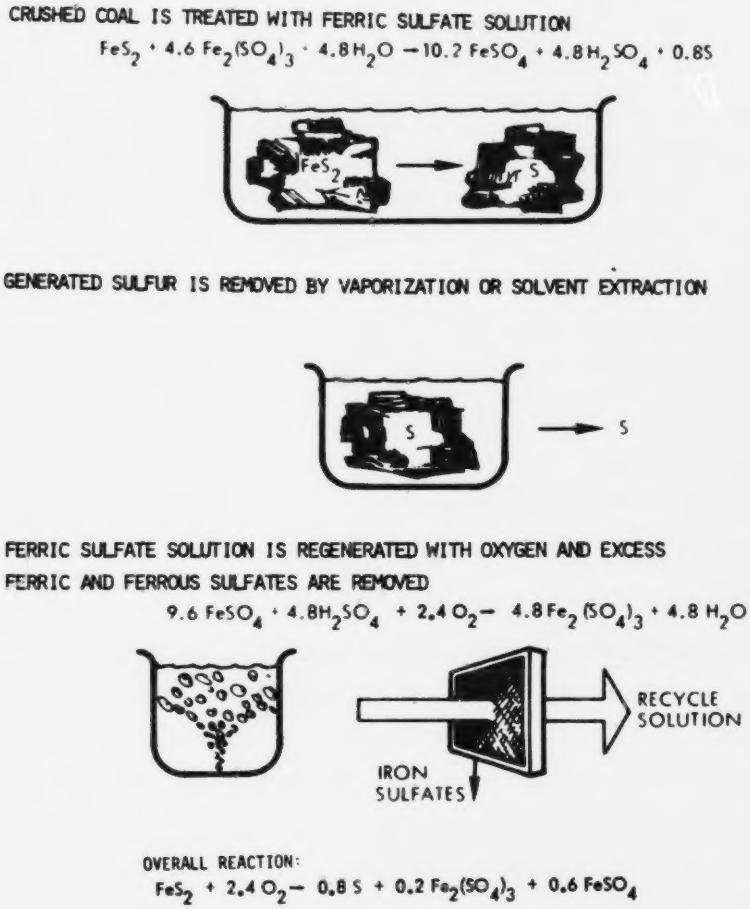
4. Process parameters necessary to achieve optimum residual elemental sulfur and sulfate removal, as well as the fate of major acid soluble ash constituents such as calcium, magnesium and non-pyritic iron, should be studied.

5. Near term emphasis should be placed on Appalachian coals since the process applicability, as defined by the results from the first coals leached in this survey, appears to be greatest for this region of the county, and since 60% of current coal production in the U.S. is mined in this region.

6. Further trace metal analysis should be conducted in order to determine the conditions of optimum trace metal removal by the combination of float-sink separation with the Meyers Process.

3.0 INTRODUCTION

The Meyers Process utilizes a regenerable aqueous ferric sulfate leaching unit to chemically convert and remove the pyritic sulfur content of coal as elemental sulfur and iron sulfate. In addition, the ash content of the coal is decreased by 10 to 40% and the heat content per unit weight increases by as much as 11%. The process chemistry for both leaching and regeneration is outlined in Figure 1.



CRUSHED COAL IS TREATED WITH FERRIC SULFATE SOLUTION

$FeS_2 + 4.6\,Fe_2(SO_4)_3 + 4.8\,H_2O \rightarrow 10.2\,FeSO_4 + 4.8\,H_2SO_4 + 0.8S$

GENERATED SULFUR IS REMOVED BY VAPORIZATION OR SOLVENT EXTRACTION

FERRIC SULFATE SOLUTION IS REGENERATED WITH OXYGEN AND EXCESS FERRIC AND FERROUS SULFATES ARE REMOVED

$9.6\,FeSO_4 + 4.8H_2SO_4 + 2.4\,O_2 \rightarrow 4.8Fe_2(SO_4)_3 + 4.8\,H_2O$

OVERALL REACTION:

$FeS_2 + 2.4\,O_2 \rightarrow 0.8\,S + 0.2\,Fe_2(SO_4)_3 + 0.6\,FeSO_4$

Figure 1. Pyritic Sulfur Removal Process Chemistry

The detailed chemistry, reaction kinetics, and engineering and economic viability of the process were established under an Environmental Protection Agency sponsored bench-scale program (Contract No. EHSD 71-7) for evaluation of the Meyers Process(1). Because of the success of the bench-scale program and the national need for sulfur oxide control technology, the process is now in a pilot plant design phase.

Other major methods which offer promise for the control of sulfur oxides from coal burning stationary sources include: flue gas scrubbing, coal liquefaction, and physical cleaning. These alternative methods are compared to the Meyers Process in the following discussion.

Chemical desulfurization has some inherent advantages over flue gas scrubbing for sulfur oxide control in that: a) application of this process requires no major modification of existing or new power plant facilities or of power plant operation, b) sulfur is removed from coal directly as elemental sulfur and iron sulfate, and in relatively small amounts (e.g., approximately 230,000 tons/yr of these by-products from reducing 3.2×10^6 tons/yr of a 4% sulfur coal to 0.8% sulfur, versus 1,000,000 tons/yr of a gypsum sludge throwaway material for comparable sulfur oxide removal using non-regenerable lime-scrubbing). This second advantage does not apply, of course, when comparing the Meyers Process to the regenerable flue gas scrubbing processes now under investigation. The iron sulfates from the Meyers Process may be converted to an insoluble basic iron sulfate form by calcining, may be used to start up additional process plants, or may possibly be sold as a chemical product in some locations.

The Meyers Process has advantages over coal liquefaction in that: (a) operation under conditions of 100°C to 130°C, ambient to 100 psig is possible, while coal liquefaction requires temperatures of 400-500°C and pressures in excess of 1,000 psi; (b) a thermal efficiency of greater than 90% is obtained, compared with a thermal efficiency for coal liquefaction of approximately 60-70% (this is an important factor in the conservation of the overall U.S. energy base); and (c) only air or oxygen is required as a consumable chemical, while liquefaction requires at least 1 to 2% by weight hydrogen or synthesis gas and for catalytic liquefaction, a significant amount of catalyst is found to be unrecoverable. However, coal liquefaction is capable of reducing a broader range of coals to meet air quality standards.

The Meyers Process has advantages over physical cleaning (or separation by physical methods of coal into rock-rich and rock-lean portions) in that: (a) large quantities of waste products are not generated (e.g., for typical physical cleaning of coal, which is basically conducted to remove non-combustible rock, 5-10% of the carbon content of the coal is discarded along with the rock-rich fraction, giving rise to a secondary pollution problem of acid drainage from tailings. For deep cleaning of coal, whose purpose is to remove a large quantity of the pyritic sulfur, up to 30% or 40% by weight of the coal may be discarded, giving rise not only to an acid drainage problem but to physical and combustion hazards due to the mass of reject); (b) pollutants are converted into small amounts of potentially useful chemicals (e.g., elemental sulfur and iron sulfate); and (c) consistent and greater reduction in overall pyritic sulfur content can be achieved.

Because of the widespread application of physical cleaning techniques for removal of non-combustible rock from coal (which includes some pyrite), the physical cleaning process deserves to be compared directly to the Meyers Process for applicability in meeting the emission standards for sulfur oxides. Indeed, in actual practice simple coal washing may well be used prior to the Meyers Process to provide an improved coal product containing both minimum ash and minimum sulfur, as well as optimum heating value.

Therefore, an EPA sponsored program for a survey of the "Applicability of the Meyers Process for Chemical Desulfurization of U.S. Coal" (Contract No. 68-02-0647) was established to determine the potential of the Meyers Process to desulfurize U.S. coals and to establish a comparison with physical cleaning of coal. It is significant to note that both processes are amenable to simple laboratory testing: the Meyers Process, through chemical leaching with ferric sulfate solution as described in Figure 1; and physical cleaning, through utilization of float-sink testing in dense media. In addition, it was a further objective of the program to determine the fate of minor elements commonly found in domestic coals during chemical leaching. The detailed results of that initial survey program were complete in April 1974 and presented in a report(2). This present report covers the results of both the above-mentioned initial program and a contract modification which extended the program scope to include additional coal mines. The detailed data obtained in the first program are not repeated here.

The potential of the Meyers Process to provide a means to meet federal standards of performance for new stationary sources is high. The Appalachian Coal Basin is an illustrative example. This coal region has particular importance as it provides 60% of current U.S. coal production, with 22 billion tons of identified and recoverable reserves, and is also the major single area of U.S. sulfur oxide air pollution. Currently, approximately 90% of the coal mined for utility use in the Appalachian Basin exceeds the sulfur content required to meet the sulfur dioxide emission standard of no greater than 1.2 lbs of SO_x emitted per million btu of input energy. However, predictions made on the basis of available sulfur forms data show that application of the chemical removal process can increase the quantity of Appalachian coal which is capable of meeting the performance standard by a factor of four, to nearly 40%, at 95% pyritic sulfur removal. (Indeed, the results of the survey program to date show that eleven of the twenty-three Appalachian coals evaluated (48%) were reduced to 0.6-0.9% w/w sulfur and were consistent with the federal standard.) In addition, many of the Appalachian coals could meet state standards for existing sources using the Meyers Process.

There are 23 major coal mining districts in the United States having several hundred identifiable coals, all of which vary significantly in composition; i.e., ash content, carbon content, sulfur content, pyrite distribution, etc. Thus, in order to establish the applicability of chemical removal of pyritic sulfur from coal process technology for sulfur oxide pollution control in the United States, the amount of sulfur which may be removed from representatives of the widest possible variety of coals must be determined. Consequently, this survey program evaluates 20 U.S. additional coals from mines in the Appalachian and Eastern Interior coal basins of the United States.

This report of the survey program contains data on over 115 coal extractions and 540 sets of coal float-sink determinations, necessitating more than 6,000 separate chemical and spectroscopic analyses. Therefore, the following guide is provided for the readers who wish to focus their attention in a specific area. Program results are presented in four major areas:

- Selection, sampling and preparation of coals
- Chemical removal of pyritic sulfur
- Float-sink studies
- Evaluation of trace element changes

These sections are followed by references, a glossary, and appendices. Those readers desiring to review the experimental data obtained for removal of pyritic sulfur from coal are directed to Sections 4.1, 4.3 and 4.4 (p. 10, 20, and 64, respectively), as well as to the appendix tables cited in these sections. Those readers desiring the selection criteria of coals for the survey are directed to Section 4.2, while those readers interested in experimental methods and sample techniques and preparation are directed to Sections 4.2 and 4.3 (p. 13 and 20, respectively). Float-sink (washability) studies are reported in Section 4.4 (p. 64) and the trace element studies are presented in Section 4.5 (p. 68).

4.0 PROGRAM RESULTS

The program results are presented in the five sections to follow: (1) Summary, (2) Selection, Sampling and Preparation, (3) Chemical Removal of Pyritic Sulfur, (4) Float-Sink Testing, and (5) Removal of Trace Elements in Coal.

4.1 SUMMARY

The Meyers Process is operable over a wide range of conditions (e.g., 100°C-130°C, coal top sizes of 1/4" to 200 mesh x 0, pressures from ambient to 100 psig, and both with and without concurrent regeneration of leach solution). Detailed discussions of the data obtained utilizing these variations are presented in separate reports covering the bench-scale programs(1,3).

A set of reaction conditions amenable to laboratory testing which are within the above range of variables was selected for this survey program. More specifically, testing was conducted at approximately 100°C and ambient pressure, and the leach solution was periodically changed in order to maintain reasonable reaction rates. Each coal was found to require specific conditions for maximum pyrite removal and total sulfur content reduction relative to one or more of the following factors: reaction time, coal particle size, degree and type of washing for sulfate removal, and excess utilization of ferric ion. More than one reaction trial was often necessary for identification of the conditions for high pyrite removal.

A summary of the best results to date for chemical removal of pyritic sulfur and the optimal results for conventional coal washing (float-sink evaluation) are shown in Table 1 in terms of total sulfur changes. The table describes the results obtained on coals which contained sufficient pyritic sulfur for accurate sulfur removal determination (i.e. >0.25% w/w). The Edna, Belle Ayr, and Walker mines were below this limit and therefore do not appear in the table. Actual total sulfur values before and after chemical removal are shown in Columns 4 and 5. These may be compared with Column 6, which shows sulfur values which could be obtained for full process optimization (at 95% pyrite removal with no increase in starting

Table 1

SUMMARY OF PYRITIC SULFUR REMOVAL RESULTS

Mine	Seam	State	Total Sulfur w/w in Coal[a]			Meyers Process Pyrite Conversion % w/w	Meyers Process Total Sulfur Decrease % w/w	% Sulfur in Coal[b] After Float-Sink
			Initial	After Meyers Process				
				Current Results	95% Removal[c]			
Navajo	Nos. 6, 7 & 8	N. Mexico	0.8	0.6	0.5	90	25	---
Kopperston No. 2	Campbell Creek	W. Virginia	0.9	0.6	0.5	92	33	0.8
Harris Nos. 1 & 2	Eagle & No. 2 Gas	W. Virginia	1.0	0.8	0.5	94	23	0.9
Colstrip	Rosebud	Montana	1.0	0.6	0.7	83	30	---
Warwick	Sewickley	Pennsylvania	1.4	0.7	0.3	92	54	1.0
Marion	Upper Freeport	Pennsylvania	1.4	0.7	0.5	96	50	1.2
Mathies	Pittsburgh	Pennsylvania	1.5	0.9	0.5	95	36	1.7
Isabella	Pittsburgh	Pennsylvania	1.6	0.7	0.6	96	54	1.5
Orient No. 6	Herrin No. 6	Illinois	1.7	0.9	0.4	96	44	1.4
Lucas	Middle Kittanning	Pennsylvania	1.8	0.6	0.4	94	64	0.7
Jane	Lower Freeport	Pennsylvania	1.8	0.7	0.5	91	63	0.8
Martinka	Lower Kittanning	W. Virginia	2.0	0.6	0.7	92	70	0.8
North River	Corona	Alabama	2.1	0.9	0.7	91	55	2.2
Humphrey No. 7	Pittsburgh	W. Virginia	2.6	1.5	1.1	91	42	1.9
No. 1	Mason	E. Kentucky	3.1	1.6	1.2	90	48	2.3
Bird No. 3	Lower Kittanning	Pennsylvania	3.1	0.8	0.4	96	75	1.5
Williams	Pittsburgh	W. Virginia	3.5	1.7	1.4	96	50	2.3
Shoemaker	Pittsburgh	W. Virginia	3.5	1.7	1.4	96	51	3.6
Meigs	Clarion 4A	Ohio	3.7	1.9	1.6	93	48	2.8
Fox	Lower Kittanning	Pennsylvania	3.8	1.6	0.8	93	57	2.0
Dean	Dean	Tennessee	4.1	2.1	1.6	94	49	3.0
Powhattan No. 4	Pittsburgh No. 8	Ohio	4.1	1.9	1.7	99	53	3.3
Eagle No. 2	Illinois No. 5	Illinois	4.3	2.0	1.8	94	54	2.9
Star	No. 9	W. Kentucky	4.3	2.5	1.9	91	43	3.0
Robinson Run	Pittsburgh	W. Virginia	4.4	2.2	1.6	97	50	3.0
Homestead	No. 11	W. Kentucky	4.5	2.4	1.5	93	47	3.2
Camp Nos. 1 & 2	No. 9 (W. Ky.)	W. Kentucky	4.5	2.0	1.8	99	55	2.9
Ken	No. 9	W. Kentucky	4.8	2.8	2.1	91	42	3.5
Delmont	Upper Freeport	Pennsylvania	4.9	1.0	0.6	96	80	2.1
Muskingum	Meigs Creek	Ohio	6.1	3.2	2.6	94	47	4.4
Weldon No. 11	Des Moines No. 1	Iowa	6.4	2.2	1.4	92	65	3.9
Egypt Valley No. 21	Pittsburgh No. 8	Ohio	6.6	2.7	1.7	93	59	4.6

[a] Dry, moisture-free basis.

[b] 1.90 Float material, 14 mesh x 0, is defined here as the limit of conventional coal cleaning (See Section 4.4)

[c] Sulfur content of coal at 95% pyrite removal and no increase in sulfate or measured organic sulfur content.

sulfate or measured organic sulfur content). Thus, for example, although 99% pyrite conversion was obtained for the Camp Nos. 1 and 2 mines, the total sulfur was reduced to 2.0%, not the theoretical 1.8%, due to a slight measured increase in other sulfur forms.

Because of the widespread application of physical cleaning techniques for removal of non-combustible rock (which includes varying amounts of pyrite) from coal (along with some carbon), float-sink fractionation was performed in order to define the relative utility of washing and chemical desulfurization for each coal. The results which are shown in Table 1, indicate that: a) the Meyers Process, at its current state of development, removed 83-99% of the pyritic sulfur content of the 32 coals studied, resulting in total sulfur content reductions of 25 to 80%, b) eleven (34%) of the coals were reduced in sulfur content to the 0.6 - 0.8% sulfur levels generally consistent with the federal standard for new stationary sources and many state standards, c) in all cases, the Meyers Process removed significant to very large increments of sulfur over that separable by physical cleaning, and d) in one case, the Mathies mine, coal cleaning resulted in a sulfur content increase.

State emission regulations for discharge of sulfur oxides from utility and large industrial power plants can also be met by application of the Meyers Process. For example, the Pennsylvania state standard for eight air basins is approximately 1.1% sulfur, for coal of 25 x 10^6 btu/ton. Several of the tested Pennsylvania coal mines (Marion, Mathies, Isabella, Bird No. 3 and Delmont) meet this standard after chemical desulfurization but do not meet the standard after efficient physical cleaning. These coals could also be transported to Michigan, New Jersey or New York to meet their state standards of approximately 1.0% and 1.8% and 2.4% sulfur, respectively. Two of the Ohio coal mines (Meigs and Powhattan No. 4) would meet the "28 county standards" of approximately 2% sulfur for the state of Ohio after treatment by the Meyers Process, whereas efficient cleaning of these coals reduces their sulfur content to only 2.8% and 3.3%, respectively.

The Orient No. 6 mine of Illinois meets the Chicago area standard of 1.29% sulfur after chemical desulfurization but does not meet the standard after physical cleaning. The Camp Nos. 1 and 2 mines in Western Kentucky meet the state standard for "Priority 3" regions of less than 2.3% sulfur after treatment by the Meyers Process, whereas physical cleaning reduces the total content of this coal to 2.5%. The Humphrey No. 7 mine is reduced to 1.5% sulfur, which meets the West Virginia standards for "Regions 2 and 3" of 1.7 and 2%,respectively, whereas physical cleaning reduces the sulfur content to 1.9%. The Weldon mine in Iowa is reduced to 2.3% sulfur by the Meyers Process which meets the state requirement of approximately 3.1% sulfur. Physical cleaning does not meet the standard, reducing the sulfur content to 3.8%.

Process improvements, such as more efficient residual sulfur and sulfate removal, will cause most coals to be further reduced in sulfur content to the "95% removal" level shown in Column 6 of Table 1.

In the production of clean fuel using commercial practices, it is very likely that an optimum process cost and product will be obtained by physically cleaning coal prior to ferric sulfate leaching, in order to remove rock and some of the larger pyrite particles. There are preliminary indications that the efficiency of the Meyers Process may be enhanced by utilization of physically cleaned coal, resulting in faster rates, greater total removal, and reduced ash dissolution.

Results from this chemical desulfurizaton survey also showed that silver, arsenic, cadmium, chromium, copper, manganese, nickel, antimony, and zinc could be substantially removed from many of the coals during the Meyers Process treatment.

The detailed results are presented in the following five sections and in the cited Appendix divisions.

4.2 METHODOLOGY OF SELECTION, SAMPLING AND PREPARATION OF COALS

TRW selected thirty-five coal mines which were sampled in two groups. The data obtained for the first group of fifteen mines has already been reported(2), but will be included in summary form in this report, in order to substantiate correlations and conclusions drawn from the data for all the coals. The data obtained in the second group of twenty mines is new and is completely reported herein. The mine selections were made on the basis of the following criteria:

a) Representation of the widest possible variety of coal beds, coal regions, and coal rank;

b) High production and reserves;

c) Sulfur content in coal sufficiently high to require control of sulfur oxide emissions from combustion.

The selected mines, the annual production of each mine in 1972(4), and the analysis summary of each group of coal samples are given in Tables 2, 3, 4, and 5. The following sections present a summary of the

Table 2

GROUP 1
INITIAL COAL SELECTION

CATEGORY	STATE	COUNTY	MINE	SEAM	1972 Production 000 Tons	COMPANY
Bituminous Coal Appalachian Coal Basin	Pennsylvania	Greene	Warwick	Sewickley	1,714	Duquesne Light Company
	Ohio	Belmont	Egypt Valley No. 21	Pittsburgh No. 8	4,223	Consolidation Coal Company
	Pennsylvania	Armstrong	Jane Nos. 1 & 2	Lower Freeport	1,999	Rochester & Pittsburgh Coal Company
	West Virginia	Monongalia	Humphrey No. 7	Pittsburgh	3,008	Consolidation Coal Company
	Maryland	Garrett	Walker	Upper Kittanning	201	Buffalo Coal Company
	Pennsylvania	Clarion	Fox	Lower Kittanning	2,036	C&K Coal Co., Subsidiary Gulf Resources Chemical Corp.
	Kentucky (East)	Harlan	No. 1	Mason	234	Dixie Fuel Company
Bituminous Coal Eastern Interior Coal Basin	Illinois	Gallatin	Eagle No. 2	Illinois No. 5	1,100	Peabody Coal Company
	Kentucky (West)	Union	Camp Nos. 1 & 2	No. 9 Seam	2,086	Peabody Coal Company
	Illinois	Jefferson	Orient No. 6	Herrin No. 6	1,843	Freeman Coal Mining Company
Bituminous Coal Western Interior Coal Basin	Iowa	Marion	Weldon	Des Moines No. 1	103	Weldon Coal Company
Sub-Bituminous Coal & Lignites Western Coals	Colorado	Routt	Edna	Wadge	875	Pittsburgh & Midway Coal Mining Company
	New Mexico	San Juan	Navajo	Nos. 6,7,8	6,898	Utah International Company
	Wyoming	Campbell	Belle Ayr	Roland-Smith	33[d]	Amax Corporation
	Montana	Rosebud	Colstrip	Rosebud	5,500	Western Engergy Corporation

[d] Mine under development, projected production 5,440,000 metric tons/year (6,000,000 tons/year)

Table 3

GROUP 2
PRESENT COAL SELECTION

CATEGORY	STATE	COUNTY	MINE	SEAM	1972 Production 000 Tons	COMPANY
Bituminous Coal - Appalachian Coal Basin	Ohio	Meigs	Muskingum	Meigs Creek No. 9	4,310	Central Ohio Coal Company
	East Ohio	Monroe	Powhattan No. 4	Pittsburgh No. 8	691	Quarto Mining Company, Subsidiary of North American Coal Company
	Pennsylvania	Fayette	Isabella	Pittsburgh	722	National Mines Corporation
	Pennsylvania	Washington	Mathies	Pittsburgh	2,205	Mathies Coal Company
	West Virginia	Marion	Williams	Pittsburgh	1,045	Consolidation Coal Company
	West Virginia	Harrison	Robinson Run	Pittsburgh	n.a.*	Consolidation Coal Company
	West Virginia	Marshall	Shoemaker	Pittsburgh	1,643	Consolidation Coal Company
	Pennsylvania	Westmoreland	Delmont	Upper Freeport	426	Eastern Associated Coal Corporation
	Pennsylvania	Indiana	Marion	Upper Freeport	436	Tunnelton Mining Company
	Ohio	Columbiana	Lucas	Middle Kittanning	n.a.	Buckeye Coal Mining Company
	Pennsylvania	Somerset	Bird No. 3	Lower Kittanning	955	Island Creek Coal Company
	West Virginia	Logan	Martinka	Lower Kittanning	n.a.	American Electric Power Company
	Ohio	Meigs	Meigs	Clarion 4A	n.a.	American Electric Power Company
	Tennessee	Scott	Dean	Dean	60	Royal Dean Coal Company
	West Virginia	Wyoming	Kopperston No. 2	Campbell Creek	1,332	Eastern Associated Coal Corporation
	West Virginia	Boone	Harris Nos. 1 & 2	Eagle & No. 2 Gas	1,718	Eastern Associated Coal Corporation
	Alabama	Jefferson	North River	Corona	n.a.	Republic Steel Corporation
Bituminous Coal-Eastern Interior Coal Basin	West Kentucky	Ohio	Homestead	No. 11	2,469	Peabody Coal Company
	West Kentucky	Ohio	Ken	No. 9	1,536	Peabody Coal Company
	West Kentucky	Hopkins	Star	No. 9	1,494	Peabody Coal Company

*Not currently available.

rationale for selection, a description of the sampling of the coals, and a discussion of sample preparation for testing at TRW. A detailed discussion of the coals and mines selected and maps showing the geographic distribution of the mines and seams are given in Appendix A.

4.2.1 Selection of Coals

Using the above criteria, a total of twenty-four of the mines was selected from the Appalachian Coal Basin. This large number was chosen since nearly 70% of current U.S. production comes from this region, and 272 x 10^9 metric tons (300 x 10^9 tons) of reserves (800 years supply at current production) still exist, although only 10-15% of the coal now mined can meet the federal standards for new stationary sources. Furthermore, much of the coal is high in pyritic sulfur, thus making it amenable to treatment. This coal is also closest to the major markets. The mines (Tables 2, 3, 4, and 5) were selected to represent a wide geographic

Table 4

COAL ANALYSIS SUMMARY INITIAL FIFTEEN COALS[a]

Mine	Seam	As Received Basis		Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
		Rank	Moisture % w/w	Total	Pyritic	Sulfate	Organic	Ash	Volatiles	Fixed Carbon	Heat Content btu
Warwick	Sewickley	hvAb	1.50	1.37	1.09	0.01	0.27	40.47	27.77	31.76	8612
Egypt Valley No. 21	Pittsburgh No. 8	hvAb	2.07	6.55	5.07	0.14	1.34	25.29	36.12	38.59	10594
Humphrey No. 7	Pittsburgh	hvAb	1.63	2.58	1.59	0.01	0.98	9.88	37.66	52.46	13631
Fox	Lower Kittanning	hvAb	1.83	3.83	3.09	0.05	0.69	13.55	38.33	48.12	12973
Walker	Upper Kittanning	lvb	2.07	0.71	0.07	0.00	0.64	16.67	18.89	64.44	12602
Jane Nos. 1 & 2	Lower Freeport	hvAb	1.17	1.85	1.44	0.00	0.41	21.75	30.07	48.18	11932
No. 1	Mason	hvAb	2.22	3.12	1.98	0.08	1.06	11.39	38.91	49.70	13054
Eagle No. 2	Illinois No. 5	hvAb	3.31	4.29	2.64	0.04	1.61	26.53	34.30	39.17	10566
Camp Nos. 1 and 2	Seam No. 9	hvBb	3.99	4.51	2.80	0.06	1.65	21.13	35.86	43.01	11105
Orient No.6	Herrin No. 6	hvAb	3.51	1.66	1.30	0.01	0.36	22.51	31.67	45.82	11163
Weldon	Des Moines No. 1	hvCb	13 29	6.39	5.24	0.15	1.00	15.74	40.62	43.64	11760
Edna	Wadge	hvCb	8.41	0.75	0.14	0.00	0.61	9.13	40.65	50.qq	11246
Navajo	Nos. 6,7,8	hvCb	11.07	0.81	0.28	0.03	0.50	25.29	35.51	39.20	10050
Belle Ayr	Roland-Smith	subA	19.14	0.76	0.22	0.03	0.54	7.55	47.11	45.34	12034
Colstrip	Rosebud	subB	20.41	1.01	0.34	0.00	0.67	10.38	43.09	46.53	11591

[a] For a complete set of data, see Reference 2.

distribution of the seams and those having large reserves and high production (Kittanning, Pittsburgh, and Freeport), with a lesser effort being made to get a wide selection of stratigraphic groups. From a stratigraphic standpoint, these mine selections range from the Sewickley Seam, which is relatively young, to the Eagle and No. 2 Gas Seams, which are relatively old.

A group of six coals was selected from the Eastern Interior Coal Basin representing the Illinois No. 5 (Kentucky No. 9), and the Illinois (Herrin) No. 6 (Kentucky No. 11) seams. Less emphasis was placed on this region due to its smaller production and the fact that the generally higher organic sulfur contents (1.5-2.5%) of these coals make them less able to meet pollution control standards by pyritic sulfur removal alone.

Table 5

COAL ANALYSIS SUMMARY[a]
PRESENT (FINAL) TWENTY COALS

Mine	Seam	As Received Basis		Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
		Rank	Moisture % w/w	Total	Pyritic	Sulfate	Organic	Ash	Volatiles	Fixed Carbon	Heat Content btu
Muskingum	Meigs Creek No. 9	hvAb	3.36	6.08	3.65	0.06	2.37	21.68	36.36	41.96	11014
Powhattan No. 4	Pittsburgh No. 8	hvAb	2.10	4.12	2.57	0.19	1.36	37.17	29.01	33.82	8603
Isabella	Pittsburgh	hvAb	1.57	1.57	1.07	0.04	0.46	42.22	24.69	33.09	8216
Mathies	Pittsburgh	hvAb	2.15	1.46	1.05	0.04	0.37	41.01	24.53	34.46	8154
Williams	Pittsburgh	hvAb	1.28	3.48	2.23	0.04	1.21	13.18	38.64	48.18	13013
Robinson Run	Pittsburgh	hvAb	0.96	4.38	2.89	0.06	1.43	13.36	38.88	47.76	12962
Shoemaker	Pittsburgh	hvAb	1.51	3.51	2.19	0.05	1.27	33.48	31.13	35.39	9495
Delmont	Upper Freeport	hvAb	0.77	4.89	4.56	0.08	0.25	27.18	28.33	44.49	11012
Marion	Upper Freeport	mvb	1.84	1.37	0.90	0.02	0.45	26.40	24.45	49.15	11046
Lucas	Middle Kittanning	hvAb	3.88	1.79	1.42	0.05	0.32	8.68	35.30	56.02	13451
Bird No. 3	Lower Kittanning	lvb	0.84	3.14	2.87	0.05	0.22	30.23	16.18	53.59	10550
Martinka	Lower Kittanning	hvAb	1.84	1.96	1.61	0.09	0.26	49.64	21.60	28.76	7552
Meigs	Clarion 4A	hvBb	4.77	3.73	2.19	0.06	1.48	26.53	34.92	38.55	10246
Dean	Dean	hvAb	1.06	4.09	2.62	0.15	1.32	17.28	36.91	45.81	12107
Kopperston No. 2	Campbell Creek	hvAb	1.38	0.91	0.47	0.03	0.41	30.15	23.89	45.96	10957
Harris Nos. 1&2	Eagle & No. 2 Gas	hvAb	1.72	1.00	0.49	0.03	0.48	18.63	26.86	54.51	12414
North River	Corona	hvAb	1.57	2.06	1.42	0.07	0.57	49.25	23.19	27.56	7693
Homestead	No. 11	hvBb	5.41	4.46	3.11	0.10	1.25	16.56	33.14	50.30	11935
Ken	No. 9	hvBb	4.76	4.83	2.85	0.26	1.72	15.08	35.26	49.66	12099
Star	No. 9	hvBb	6.13	4.32	2.60	0.24	1.50	13.90	33.94	52.16	12308

[a] For a complete set of data, see Appendix C.

A single sample from the Weldon Mine, Des Moines No. 1 Seam, was chosen from the Western Interior Basin.

A group of four coals was selected from the remaining coal basins in the western half of the United States. Even though this area contains more than half of all U.S. reserves, the selections were deliberately limited because of present low production, sulfur contents generally less than 1.0%, and pyritic sulfur contents so low (<0.25%) that the results of chemical extraction would be difficult to measure.

4.2.2 Sampling of Coals

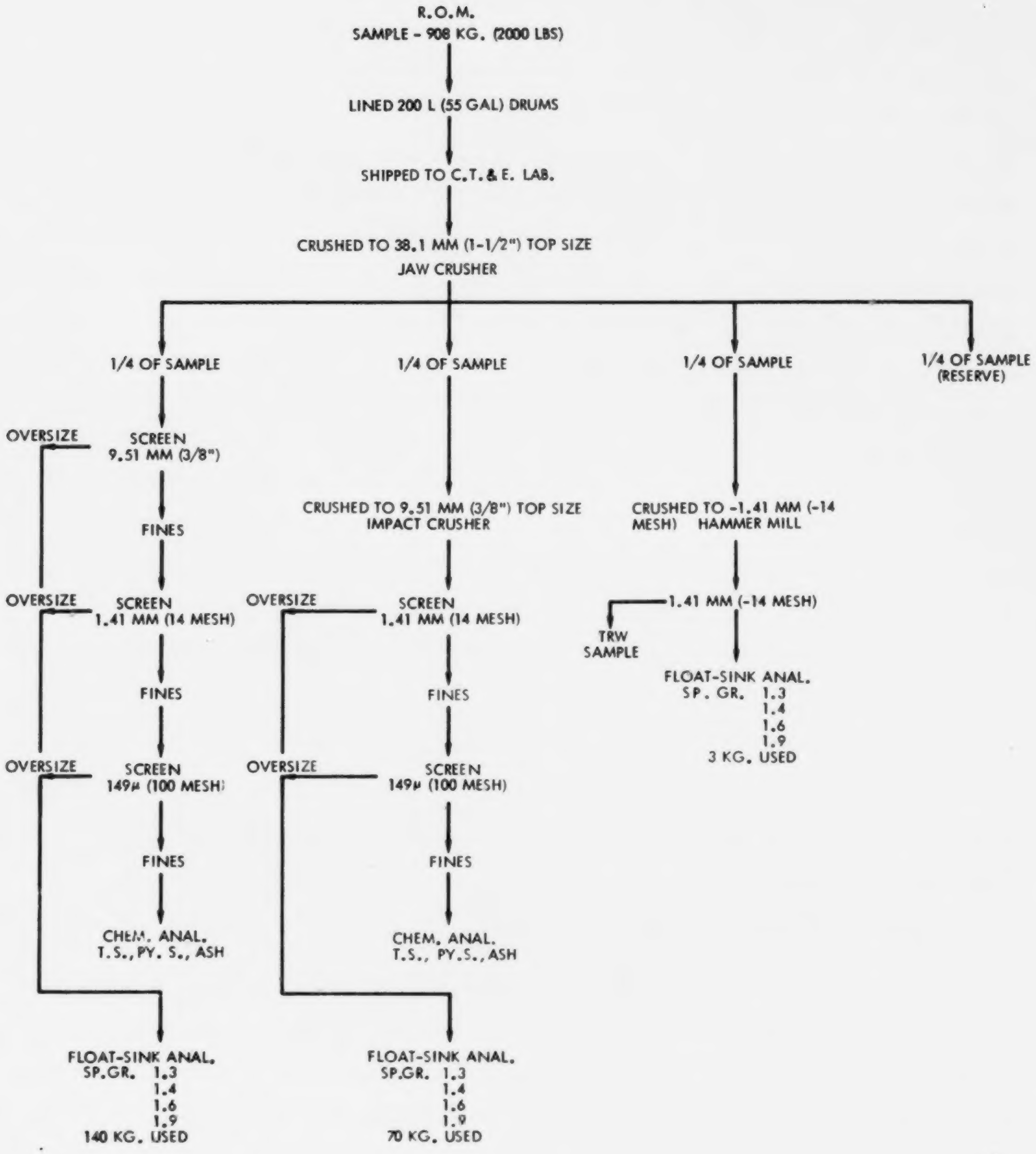
Samples containing 908 kg (one ton) of raw run-of-mine (ROM) coal were collected from each mine. The samples were taken in increments that represented at least a half day's production. Samples were collected in accordance with ASTM Standard D2234(6) with the following preferences: automatic samples, stopped belt increments, and, if necessary, full falling stream intercepts. Auger sampling of unit trains in certain instances was also utilized in cases where it could be shown that the trains contained only ROM coal from a single seam and mine.

The samples were sealed in plastic-lined drums (six per mine) for shipment to Commercial Testing and Engineering Laboratory (CT&E) where each 908 kg (one ton) gross sample was crushed to 38.1 mm x 0 (1-1/2" x 0) by a jaw crusher, divided into four parts and treated as follows:

- A 38.1 mm x 0 (1-1/2" x 0) fraction was taken for float-sink fractionation,
- A second part was crushed to 9.51 mm x 0 (3/8" x 0) for float-sink fractionation,
- A third part was crushed to 1.41 mm x 0 (14 mesh x 0) for float-sink fractionation. An 11 kg sample of this material was also sent to TRW for chemical processing to remove pyritic sulfur.
- The remaining part was held in reserve.

Float-sink fractionation of portions 1, 2 and 3 above was performed with organic liquids at 1.30, 1.40, 1.60 and 1.90 specific gravities. The resulting fractions were analyzed for ash, total sulfur, and pyritic sulfur on a dry basis. The results were then used to calculate washability tables in order to determine cumulative recoveries and rejects at the various specific gravities. Figure 2 illustrates the sequence of sampling and testing.

The procedures used to collect each of the current twenty 908 kg samples are described in Appendix A, while the procedures used for the initial fifteen coals have been reported previously(2).



R.O.M.
SAMPLE - 908 KG. (2000 LBS)
LINED 200 L (55 GAL) DRUMS
SHIPPED TO C.T.& E. LAB.
CRUSHED TO 38.1 MM (1-1/2") TOP SIZE
JAW CRUSHER
1/4 OF SAMPLE
1/4 OF SAMPLE
1/4 OF SAMPLE
1/4 OF SAMPLE
(RESERVE)
OVERSIZE
SCREEN
9.51 MM (3/8")
FINES
OVERSIZE
SCREEN
1.41 MM (14 MESH)
FINES
OVERSIZE
SCREEN
149μ (100 MESH)
FINES
CHEM. ANAL.
T.S., PY. S., ASH
FLOAT-SINK ANAL.
SP.GR. 1.3
1.4
1.6
1.9
140 KG. USED
CRUSHED TO 9.51 MM (3/8") TOP SIZE
IMPACT CRUSHER
OVERSIZE
SCREEN
1.41 MM (14 MESH)
FINES
OVERSIZE
SCREEN
149μ (100 MESH)
FINES
CHEM. ANAL.
T.S., PY.S., ASH
FLOAT-SINK ANAL.
SP.GR. 1.3
1.4
1.6
1.9
70 KG. USED
CRUSHED TO -1.41 MM (-14
MESH) HAMMER MILL
1.41 MM (-14 MESH)
TRW
SAMPLE
FLOAT-SINK ANAL.
SP. GR. 1.3
1.4
1.6
1.9
3 KG. USED

Figure 2. U.S. Bureau of Mines Sampling, Handling System Amended

4.2.3 Coal and Sample Preparation at TRW

An 11 kg (25 lb) sample of coal ground to 1.41 mm x 0 (14 mesh x 0) was shipped from CT&E to TRW in a sealed polyethylene bag inside a 5-gallon can. If any surface moisture was observed upon receipt at TRW, the coal was spread on a polyethylene sheet in a fume hood and allowed to air dry from 4 to 6 hours. This gross sample was then reduced by riffling to obtain 1600-2000g portions. One sample was stored under nitrogen or argon in a glass container as a reserve, and another was ground in a disintegrator with a 0.58 mm screen. After several passes, the entire lot was sieved using a 149μ (100 mesh) screen. All oversize material was then passed through the grinder several more times and resieved; this process was repeated until more than 99% of the material passed through a 149μ (100 mesh) screen. The remaining fraction of 1%, which was composed of slate and other rock-like material, was discarded. The entire lot of 149μ x 0 (100 mesh x 0) coal was then thoroughly mixed by conventional cone and quartering techniques on a polyethylene sheet. The coal was then bottled as 100.0 g samples in containers that had been flushed with nitrogen or argon. In order to guarantee relatively uniform samples, the coal was periodically mixed during this process. It was found that when the coal was 100% 149μ x 0 (100 x 0 mesh), in most cases 91% would pass a 105μ (150 mesh) screen and 70% would pass a 74μ (200 mesh) screen.

If finer coal was needed, the required amount of coal (200-300g) was quantitatively ground in a ball mill to pass a 105μ (150 mesh) or 74μ (200 mesh) screen.

4.3 CHEMICAL REMOVAL OF PYRITIC SULFUR

This section presents descriptions of the experimental methods and summarizes results from the studies involving chemical removal of pyritic sulfur from the surveyed coals. The removal of trace elements from coals as a result of the Meyers Process is described in Section 4.5, together with a discussion of the experimental methods used to determine the trace element composition.

Also included in this section are discussions of: (a) total pyritic sulfur removal and its removal as a function of time, (b) ferric ion consumption and its relationship to pyrite removal and the final heat content of coal, (c) ash changes, (d) sulfate retention, (e) changes in the organic sulfur content, and (f) miscellaneous findings.

4.3.1 Experimental Method

The reaction conditions for pyritic sulfur removal have been adapted from the previous bench scale studies (Contract EHSD 71-7)(1,3) and the previously completed Part I(2) of the survey program, for the purposes of: (a) obtaining 90-100% pyritic sulfur removal, (b) simulating process design as nearly as possible, and (c) obtaining as much quantitative data as possible. The general procedure is discussed below.

Mesh Size — Coal ground to 100 mesh x 0 was found to give the maximum extraction rates and to be most satisfactory for laboratory scale sampling. Coal ground to a finer mesh was used only if conditions warranted.

Ferric Ion Concentration — Ferric sulfate solution 1 N in ferric ion appears to be optimum, although differences due to concentration changes do not appear to be great(1,3).

Reaction Temperature — The reaction temperature was held at the reflux of 1 N ferric sulfate solution, which is approximately 102°C. This allows a reasonably high reaction rate and yet did not require pressure equipment.

A trial experiment was run for each coal (due to the high variance in the behavior of individual coals) in order to select the reaction time, mesh size, and number of leach solution changes needed for maximum pyrite removal.

Reaction Time — Each coal was leached a total of six or more hours, depending on the characteristics of the individual coal being treated.

Ferric Ion to Total Iron Ratio — Since the rate of pyrite removal is slowed substantially by ferrous ion accumulation, each coal was treated under conditions designed to keep this ratio >0.80 by one of the following methods:

- Increasing the solvent to coal ratio (w/v) from a nominal 3 to 8 used in the bench scale work to 25.

- Changing the leach solution after 3 to 6 hours of reaction or more often, if required.
- A combination of the above.

Post Sample Treatment — After treatment, the samples were thoroughly washed to remove any residual leach solution. The wet coal was extracted with toluene to remove elemental sulfur, and then dried. All sample calculations were done on a dry basis in order to eliminate variables due to wetness of the coal. Sulfur forms and proximate analysis were obtained for each treated coal sample.

In addition to the characterization of the initial and treated coal, further evaluations were performed on the 20 additional coal mines sampled for this part of the survey, in order to determine in greater detail the kinetic behavior of pyritic sulfur extraction and at the same time, to investigate potential problem areas that may arise when the Meyers Process is applied to a large variety of coals. This included an evaluation of the following items for all coal samples processed:

Rate of Pyrite Removal — Coal samples were taken periodically and analyzed for pyritic sulfur. In order to simplify rate calculations, the ratio of coal to leaching solution was kept constant by always withdrawing an equivalent amount of leach solution.

Rate of Ferric Ion Consumption — The leach solution withdrawn from the above samples was analyzed for ferrous as well as total iron in order to determine the rate of ferric ion consumption and iron balance. Additional samples were withdrawn and analyzed as necessary in order to get precise results.

Retention of Leach Solution on the Coal — Retention of the leach solution on the coal was determined by weighing the coal after filtration under a set of standardized conditions and subtracting the dry weight of the treated coal.

Retention of Sulfur Solvent — Retention of the sulfur solvent on the coal was determined by weighing the coal after filtration under a set of standardized conditions and subtracting the weight of the treated coal.

4.3.1.1 Extraction Procedure

The exact procedure used in this survey is described below:

One hundred grams of 100 mesh x 0 coal are added to 2 ℓ refluxing 1N ferric sulfate solution contained in a 4-necked, 3 ℓ glass cylindrical reaction vessel equipped with a mechanical stirrer, reflux condenser and a thermocouple attached to a recorder. Each vessel also has a stopcock at the bottom for taking samples and is heated by a specially constructed heating mantle. After the coal addition, an additional 0.5 ℓ 1N ferric sulfate solution is used to wash down the sides of the vessel. At this point, the t_0 solution sample is taken and the leaching process is considered started. Then, the reaction mixture, which is at 88 ±4°C, is rapidly brought to reflux, a process that takes 8 - 12 minutes. Leach solution samples for each analysis are collected by taking a 35 ml aliquot of the reaction mixture (the sampling procedures are discussed below) and cooling it immediately to 0°C. After cooling, the aliquot is centrifuged to remove all suspended solids and 30 ml of this is used for iron analysis. The remaining coal is washed, dried and saved for pyritic sulfur analysis.

After 4-6 hours, the heating is stopped and the reaction mixture is drained from the flask, filtered and dewatered under vacuum conditions. The final reaction volume and solution retention on the coal are determined at this time. The wet, unwashed coal is slurried with 200 ml fresh ferric sulfate solution at 30°C and added to 2 ℓ fresh 1N ferric sulfate solution at reflux. Another 300 ml ferric sulfate is then used to wash any residual coal into the flask. A t_0 leach solution sample is taken immediately and the entire reaction mixture is brought to reflux in 8 - 12 minutes. Leach solution samples are taken at regular intervals; and after a total elapsed reacton time of 10 to 24 hours, the reaction mixture is drained from the reaction flask, filtered and washed clear with 0.5 - 1.0 ℓ water.

The extracted coal is then slurried with 2 ℓ 0.2N H_2SO_4 at ∿ 80°C. This is followed by slurrying in 2 ℓ water. If scheduling does not permit the coal to be extracted with toluene immediately, it is stirred at ∿ 50°C in water for an extended period until it can be filtered and extracted.

After the extraction of residual sulfate and iron, the wet coal is transferred into a 1 ℓ round bottom flask equipped with a mechanical stirrer and Dean-Stark trap. Toluene, 400 ml, is added and the mixture is brought to reflux. This is continued until all the water is azeotroped off (approximately 0.75 - 1.25 hour and 50 - 75 ml) plus another 15 minutes. The hot solution is then filtered, washed with 50 - 75 ml toluene, and dried in a vacuum oven at 100 - 120°C. The coal is then weighed and analyzed.

4.3.1.2 Coal Sampling from Reaction Vessel

In order to determine the rate of pyrite removed from the coal, it is necessary to periodically take coal samples from the reactor for pyrite analysis. This is because the accumulation of ferrous ion in solution reflects not only the oxidation of pyrite but also a small and variable reaction with the organic matter in coal(1,2,3).

Initially, it was thought that, since 100 mesh x 0 or finer coal was being used, the coal distribution within the rapidly stirred and boiling reactor would be uniform in all directions. It soon became apparent, however, that even with all the turbulence in the reactor, a float-sink separation was taking place with the heavier particles settling in a small dead space (ca 1g) where the stopcock is attached to the bottom of the reaction vessel. This results in poor or erratic pyrite analysis in the first six hours of reaction when pyrite concentrations are high. The pyrite composition of the segregated material was found to be over 10% w/w after 1 hour of reaction for coal which initially had only 4.9% w/w pyritic sulfur. Removing this material with 200 ml leach solution, quickly adding it back through the top of the reactor, and then taking a sample before any settling took place was not successful because the heavy particles rapidly, but unevenly, sand toward the bottom of the reaction vessel. This resulted in erratic pyritic sulfur values with differences of up to 1%. In some cases, the sampling of pyrite-rich areas resulted in apparent pyritic sulfur gains of 1-3% after 1 hr of reaction. The problem was finally solved by using a "thief" technique in which an aluminum tube, designed to take a 30-40 ml sample along the entire vertical axis of the reactor, was rapidly inserted into the vessel and then closed off when it reached the bottom. In order to guarantee that the high pyrite material which collected in the bottom of the reactor was in suspension at the time the sample was taken, several 200 ml aliquots were taken out of the bottom of the reactor and poured into the top just before the sample was taken. This procedure was used on the final five coals that were treated, and good reactor-to-reactor precision and pyritic sulfur values consistent with ferrous ion accumulation were obtained.

It is also postulated that sampling problems would be substantially reduced by removal of high density material by float-sink methods. The specifics of four different methods of reaction vessel sampling, as well as the coals sampled by each method, are briefly summarized below:

> Method A: Lucas, Marion, Meigs, Mathies, Powhattan Coals. A 35 ml sample was taken from the bottom of the reactor after first removing the coal plug in the valve with 200 ml of solution. Samples from all of the coals taken during the first 5-6 hrs were low in pyrite. Precision for the Lucas, Marion and Mathies coals which had low initial pyrite (≈1%) was good; precision for the Meigs and Powhattan coals was poor. Only samples taken after 5-6 hours, when most of the pyrite is removed by chemical reaction, were considered reliable.
>
> Method B: Muskingum, Isabella, Robinson Run, Delmont, Bird No. 3, Star and Ken Coals. In this procedure the coal plug was withdrawn with 200 ml of solution and added back to the reactor just before sampling. This resulted in very poor precision between reactors and apparent increases in pyrite content during the first 3 hrs in several cases. Samples taken during these runs were considered reliable only after 8 hrs. Reasonable results were obtained for the low ash Star and Ken coals.
>
> Method C: Shoemaker and Williams Coals. An aluminum tube with an open bottom that holds 30-40 ml within the vertical axis of the reaction vessel was rapidly inserted to the bottom of the reactor; then the bottom was closed off and the tube withdrawn. This method gave good precision but may have given slightly low results, as with Method A.
>
> Method D: Martinka, Kopperstone, Harris Nos. 1 and 2, North River, Homestead and all additional (No. 3) runs on the Powhattan No. 4, Williams and Lucas Mines. Method C was modified by withdrawing the plug from the bottom of the reactor with 200 ml of solution and pouring it back into the top of the reactor. This method gave good precision and the results were considered accurate.

4.3.1.3 Precision of Sulfur Analysis

During the course of these studies, a substantial amount of sulfur analyses data was collected which included 35 sets of sulfur forms analyses on untreated coals and an additional 34 sets on the treated coals. It was the practice during this research program to process multiple samples for individual analysis rather than to perform a duplicate analysis on a single sample. In this way, all sampling and handling errors were included in each analysis, and the results would not appear artificially precise. The standard deviation for each set of these analyses was used to calculate a pooled standard deviation for each type of analysis both before and after extraction. The results of these calculations (tabulated in Table 6) show that, in all cases, precision is excellent. In addition, the precision of the analysis on the treated coals is only slightly less than that of the untreated coals, indicating that the leaching and work-up procedures were carried out in a very uniform way.

Table 6

PRECISION OF SULFUR FORMS ANALYSIS
POOLED STANDARD DEVIATIONS, % W/W ABSOLUTE

Samples (S_n)	SULFUR FORMS			
	Total	Pyrite	Sulfate	Organic
Initial (35)	0.063	0.074	0.010	0.085
Treated (34)	0.066	0.071	0.019	0.090
All (69)	0.064	0.072	0.016	0.090

4.3.1.4 Atomic Absorption Method for Pyritic Sulfur Determination

The analysis for pyritic sulfur normally requires approximately 1-5 g of coal and substantial labor for the ASTM analysis(6). Because as many as six to ten samples would be withdrawn from the chemical reactor containing 100 g coal during the course of a run, it was apparent that the method of analysis should be examined for modification that would allow a reduction in both sample size and analysis time. The following criteria were considered:

- The methods of chemical extraction of sulfate and pyritic sulfur would not be changed because they have been accepted as effective and because change would require a development effort out of scope of this contract.
- Only methods requiring 0.25-1.0 g of total sample would be considered.
- Since new methods which are characterized by both speed and accuracy for determining iron have been developed in recent years, these methods would be examined for applicability.

- The iron analysis (pyritic sulfur) should have the same accuracy and precision as the old method.

The method of sulfur extraction used was identical to the ASTM procedure[6] in which both pyritic and sulfate sulfur determinations are performed on the same sample, with the exception that a 0.7-1.0 g sample is used. Iron oxide and ferrous sulfate are first extracted with refluxing 5N HCl for 0.75 hr. The filtered and washed residue is then extracted with refluxing 5N HNO_3 for 0.5 hr to remove iron pyrite. The extract solutions are then brought up to volume for an iron analysis by the procedure described below. Sulfur is not determined directly because a small amount of organic sulfur is usually extracted by the nitric acid.

Atomic absorption spectrophotometry (AAS) was selected for pyritic iron determination for the following reasons:

a) The extraction of small amounts of organic material does not affect the determination. Hence, several steps in the ASTM procedure, which are designed to destroy organic material in order to prevent is reaction with the strong oxidizing agent used in the subsequent titrimetric determination of iron, can be eliminated.

b) The atomic absorption method for determining iron is normally free of interelement interferences.

c) Matrix effects can be eliminated by use of a dual channel atomic absorption spectrometer, such as the Fisher Jarrell-Ash instrument.

d) Extracted color does not interfere with the determination as is the case for the ASTM procedure, which has a colorimetric endpoint.

e) The method is precise, accurate, fast, and inexpensive.

The results of analysis performed by the atomic absorption and ASTM methods are summarized in Table 7. Note that in those cases where multiple analyses were performed, the precision of the AAS method is excellent. In fact, the precision obtained is that expected from a good Eschka (total)

Table 7

SULFUR FORMS ANALYSIS[a,b,c]
ATOMIC ABSORPTION VS. ASTM PROCEDURES

Sample	% w/w Pyritic Sulfur		Sample	% w/w Pyritic Sulfur	
	AAS	ASTM		AAS	ASTM
Muskingum	0.22 ± .028	0.26 ± .007	Marion	0.06 ± .021	0.05 ± .022
Powhattan No. 4	0.46 ± .064	0.43 ± .057	Mathies	0.02 ± .000	0.08 ± .000
Isabella	0.06 ± .007	0.07 ± .007	Meigs	0.18 ± .035	0.16 ± .035
Mathies	0.08 ± .000	0.02 ± .000	Powhattan	0.46 ± .064	-
Williams	0.28 ± .049	0.30 ± .035	Eagle No. 2	0.18	0.11
Robinson Run	0.08 ± .014	0.08 ± .014	Jane	0.62	0.63
Shoemaker	0.44 ± .148	0.46 ± .120	Fox	0.50	0.47
Delmont	0.22 ± .078	0.20 ± .134	Meigs[e]	0.43	0.43
Marion	0.04 ± .007	0.05 ± .014	Powhattan No. 4[e]	0.64	0.54
Lucas	0.22 ± .049	0.20 ± .007	Muskingum[e]	0.60	0.48
Bird No. 3	0.11 ± .014	0.16 ± .035	Mathies[c]	0.98 ± .007	1.05 ± .065
Martinka	0.12 ± .007	0.12 ± .007	Marion	0.84 ± .007	0.90 ± .017
Meigs	0.18 ± .035	0.16 ± .035	Powhattan No. 4	2.53 ± .000	2.57 ± .060
Dean	0.20 ± .007	0.16 ± .035	Robinson Run	2.72 ± .014	2.89 ± .190
Kopperston No. 2	0.02 ± .000	0.06 ± .035	Lucas	1.24 ± .007	1.42 ± .082
Harris No. 1 and 2	0.02 ± .000	0.07 ± .042	Williams	1.94 ± .000	2.23 ± .062
North River	0.17 ± .028	0.12 ± .021	Isabella	1.05 ± .042	1.07 ± .070
Homestead	0.22 ± .028	0.22 ± .092	Shoemaker	2.18 ± .007	2.19 ± .100
Ken	0.24 ± .050	0.30 ± .050	Meigs	1.88 ± .191	2.19 ± .030
Star	0.04 ± .021	0.08 ± .028	Bird No. 3	2.64 ± .021	2.87 ± .062
Eagle No. 2	0.25 ± .004[d]	0.19	Delmont	4.27 ± .014	4.56 ± .044
Lower Kittanning[f]	0.48 ± .038[d]	0.33 ± .035	Eagle No. 2	2.66 ± .03[d]	2.67 ± .15[d]
Lucas	0.12 ± .007	0.21 ± .034	Egypt Valley	4.70 ± .004[d]	5.07 ± .02[d]

[a] Unless otherwise noted, all analysis have been performed on two samples of treated coal.

[b] Values without standard deviation are single determinations.

[c] All values greater than 1% are untreated coal.

[d] Average of 3 determinations.

[e] Analysis from trial runs.

[f] Sample from previous bench-scale program (Ref. 3).

sulfur analysis rather than a sulfur forms analysis. The results are also substantiated by the pyritic sulfur analysis of the final 23 hr samples (see p. 32 for details of reaction conditions, including reaction times) which were determined both by the AAS method and by the standard ASTM procedure performed by an outside commercial laboratory (CT&E). The pooled standard deviation for all 20 sets of analyses was 0.032 for the AAS method but was 0.060 for the ASTM method. In addition, the number of analyses which were rechecked and found to be wrong was much greater when the ASTM procedure was used. These "outliers" are not included in the above calculations. Thus, it appears that the AAS determination of iron for the pyritic sulfur analysis gives a substantial improvement in precision over the ASTM procedure.

In all cases, the agreement with the values determined by the ASTM method is excellent, although the AAS results tend to be slightly low in certain cases. Because treatment by the Meyers Process tends to increase the amount of color extractable by nitric acid, it is possible that these small differences may partly be due to difficulty in determining the end point of the ASTM titration. In general, however, the average values as determined by both methods were statistically interchangeable, giving further indication of the validity of the accuracy of the AAS method.

The AAS and ASTM determined values of the final pyritic sulfur content of the treated coals are therefore reported without differentiation in Appendix D and the two sets of duplicates were used to calculate the pyritic sulfur removal for the 20 additional coals treated in this report.

4.3.2 Pyritic Sulfur Removal Results

Table 8 summarizes the results of the pyritic sulfur removal experiments. The percentage removal may be calculated by dividing the difference between the initial and final weight percent pyritic sulfur by the initial weight percent pyritic sulfur. However, because of the ash (both pyritic and excess) that is removed, the remaining pyritic sulfur in the treated coal is slightly concentrated, and calculation of removal on a percent basis results in a value lower than is actually the case. For this reason, a corrected value was also calculated which compares the

Table 8

SUMMARY OF PYRITIC SULFUR REMOVAL DATA[a]

Mine	Seam	Rank	Run No.	Total Rxn. Time	Leach Changes	Mesh[b]	Dry Basis Pyritic Sulfur Analysis, % W/W			Pyrite Removal % W/W		
							Initial	Treated	Removed	Nominal[c]	Corrected[d]	Std. Dev.
Warwick	Sewickley	hvAb	1-3	23	1	100	1.09 ±.086	0.09 ±.043	1.00 ±.096	92	92	4.0
			4	13	1	100		0.06	1.03	94	95	--
Muskingum	Meigs Creek No. 9	hvAb	1-2	23	1	150	3.65 ±.010	0.24 ±.031	3.41 ±.033	93	94	0.9
Egypt Valley No.21	Pittsburgh No. 8	hvAb	1-3	13-22[e]	1	100	5.07 ±.025	0.62 ±.178	4.45 ±.190	88	89	3.5
			4	13	1	200		0.38	4.69	93	93	---
Powhattan No. 4	Pittsburgh No. 8	hvAb	1-2	23	1	100	2.75 ±0.60	0.44 ±.051	2.31 ±.079	84	85	1.9
			3	23	1	200		0.04	2.71	99	99	---
Isabella	Pittsburgh	hvAb	1-2	23	0	100	1.07 ±.070	0.04 ±.0.00	1.03 ±.070	96	96	0.3
Mathies	Pittsburgh	hvAb	1-2	23	0	150	1.05 ±.065	0.05 ±.035	1.00 ±.074	95	95	3.3
Williams	Pittsburgh	hvAb	1-2	23	1	100	2.23 ±.062	0.29 ±.086	1.94 ±.072	87	88	1.7
			3	23		150		0.10	2.13	96	96	---
Humphrey No. 7	Pittsburgh	hvAb	1-3	23	1	100	1.59 ±.114	0.14 ±.055	1.45 ±.127	91	91	3.5
Robinson Run	Pittsburgh	hvAb	1-2	23.5	1	150	2.89 ±.190	0.08 ±.012	2.81 ±.190	97	97	0.5
			3	23	1	150		0.08	2.11	96	96	---
Shoemaker	Pittsburgh	hvAb	1-2	23	1	100	2.19 ±.100	0.46 ±.111	1.73 ±.149	79	80	5.1
Delmont	Upper Freeport	hvAb	1-2	23	1	200	4.56 ±.044	0.21 ±.090	4.35 ±.100	95	96	2.0
Marion	Upper Freeport	mvb	1-2	23	0	100	0.90 ±.017	0.04 ±.013	0.86 ±.021	96	96	1.5
Jane	Lower Freeport	hvAb	1-2	11-23[e]	1	100	1.44 ±.098	0.14 ±.007	1.30 ±.098	90	91	0.8
			3	23	1	100		0.63	0.81	56	60	--
Lucas	Middle Kittanning	hvAb	1-2	23	0	100	1.42 ±.087	0.21 ±.034	1.21 ±.093	85	85	2.6
			3	23	0	150		0.08	1.34	94	94	--
Bird No. 3	Lower Kittanning	[illegible]	1-2	23	1	150	2.82 ±.062	0.13 ±.034	2.74 ±.071	96	96	1.2
Fox	Lower Kittanning	hvAb	1-3	23	1	100	3.09 ±.017	0.37 ±.163	2.72 ±.164	88	89	5.3
			4	14	1	200		0.26	2.83	92	93	---
Martinka	Lower Kittanning	hvAb	1-2	23	0	100	1.42 ±.010	0.12 ±.006	1.30 ±.021	92	92	0.4
Meiggs	Clarion No. 4-A	[illegible]	1-2	23	1	100	2.19 ±.030	0.17 ±.029	2.02 ±.042	92	93	1.3

Table 8 (Cont'd)

Dean	Dean	hvAb	1-2	23	0	150	2.62 ±.087	0.17 ±.029	2.45 ±.092	94	94	1.1
No. 1	Mason	hvAb	1-3	23	1	100	1.98 ±.062	0.21 ±.045	1.77 ±.077	89	90	2.3
Kopperston No. 2	Campbell Creek	hvAb	1-2	13	0	100	0.47 ±.026	0.04 ±.029	0.43 ±.039	92	92	6.2
Harris No. 1&2	Eagle & No. 2 Gas	hvAb	1-2	23	0	100	0.49 ±.036	0.03 ±.00	0.46 ±.036	94	94	0.5
North River	Corona	hvAb	1-2	23	0	100	1.42 ±.026	0.14 ±.038	0.28 ±.046	90	91	2.7
Orient No. 6	Herrin No. 6	hvAb	1-3	23	1	100	1.30 ±.084	0.32 ±.076	0.98 ±.113	75	76	6.1
			4	23	1	200		0.12	1.18	91	92	
			5	13	1	200		0.06	1.24	95	96	
Homestead	No. 11	hvBb	1-2	23	1	100	3.11 ±.049	0.22 ±.056	2.89 ±.074	93	93	1.8
Eagle No. 2	Illinois No. 5	hvAb	1	13	2	100	2.64 ±.154	0.36	2.28	86	94	
			2	14	1	100		0.11	2.53	96	98	
			3	14	1	100		0.33	2.31	88	94	
			4	23	1	100		0.19	2.45	93	94	
Camp Nos. 1 & 2	No. 9 (W. Kentucky)	hvBb	1-3	13	1	100	2.80 ±.120	0.62 ±.210	2.18 ±.242	78	80	7.6
			4	23	1	100		0.33	2.47	88	89	
			5	23	2	200		0.02	2.78	99	99	
			6	13	1	200		0.14	2.66	95	96	
Ken	No. 9	hvBb	1-2	23	1	100	2.85 ±.038	0.28 ±.021	2.57 ±.043	90	91	0.7
Star	No. 9	hvBb	1-2	23	2	150	2.60 ±.100	0.24 ±.029	2.36 ±.104	91	91	1.2
Weldon	Des Moines No. 1	hvCb	1-3	23	2	100	5.24 ±.038	0.47 ±.099	4.77 ±.106	91	92	1.9
			4	13	1	200		0.15	5.19	97	98	
Edna	Wadge	hvCb	1-3	23	1	100	0.14 ±.015	0.06 ±.020	0.08 ±.025	57	59	15
Navajo	Nos. 6,7,8	hvCb	1-3	23	2	100	0.28 ±.044	0.04 ±.040	0.24 ±.059	86	87	14
			4	6	0	100		0.03	0.25	89	90	
Belle Ayr	Roland-Smith	subA	1-3	6-10[e]	1	100	0.22 ±.017	0.03 ±.012	0.19 ±.021	86	89	5.6
Colstrip	Rosebud	subA	1-3	12-13[e]	1-2	100	0.34 ±.015	0.06 ±.006	0.28 ±.016	82	83	1.9

[a] Walker mine omitted due to low pyritic sulfur content (0.07%). [b] 100 mesh x 0 and 200 mesh x 0 coal is symbolized as 100 and 200, respectively. [c] This value is calculated by dividing the pyritic sulfur loss in % w/w by the initial % w/w pyritic sulfur. [d] This value is calculated by dividing the number of millimoles of sulfur loss by the initial number of millimoles of pyritic sulfur. [e] Indicates different reaction times with no significant differences in results.

weight of the pyrite in the treated coal to the weight of pyrite in the untreated coal. The latter value, though harder to calculate because it requires a material balance, is more nearly accurate than the former; consequently, this value is used in the following discussions.

The results of the pyritic sulfur removal are very encouraging in that, with the exception of the very low pyrite western coals, 90-99% w/w pyritic sulfur removal was achieved for all the coals treated. The western coals were reduced to a measured 0.09-0.06% w/w pyritic sulfur, which were among the lowest values observed in the program. However, the low initial pyritic sulfur content of these coals (0.14-0.34% w/w) obscures this fact in the percentage removal calculations, where removal of only 59-89% was obtained.

The standard set of reaction conditions included a reaction time of 23 hours, one change of leach solution during the 4 to 6 hour time period, and the use of 100 mesh x 0 coal. Although high removal was achieved with the low pyritic sulfur Belle Ayr, Colstrip, Navajo and Kopperston coals using reaction times of only 6-14 hours, these conditions were insufficient for high removal from many of the other coals. Samples of the other coals were further ground to 150 or 200 mesh x 0 to expose more finely divided pyrite encapsulated in the coal and at the same time allow faster extraction, since the smaller size particles would thus present a greater surface area for reaction. The 200 mesh x 0 Camp Nos. 1 & 2 coal was run for 23 hours (Run No. 5), which resulted in 99% pyrite removal compared to 80-89% removal (Run Nos. 1-4) for 100 mesh x 0 coal. The remaining pyrite was reduced from 0.62% to 0.02% w/w. Since Run No. 5 indicated a much increased rate of removal, an additional experiment (Run No. 6) was performed with a total reaction time of 13 hours. This run resulted in 96% pyrite removal with a final pyrite content of 0.14 w/w. Another set of experiments, using 200 mesh x 0 Orient No. 6 (Run Nos. 4-5) coal, gave much better removals than obtained with 100 mesh x 0 coal. In the 23-hour run, the removal was increased from 76% to 92%, and the final pyrite content was reduced from 0.32% to 0.12% w/w. Reducing the reaction time to 13 hours gave an apparent increase in removal to 96%, with a final pyrite content of 0.06% w/w. The small discrepancy is probably the result of accumulated experimental errors.

Because of this observed increased removal during reduced reaction time, a series of 13 and 14 hour runs using 200 mesh x 0 coal was also conducted with the Egypt Valle No. 21, Powhattan No. 4, Fox, Warwick, and Weldon coals in order to check the generality of this phenomenon. These runs resulted in increased pyrite removals from 89 to 93% for the Egypt Valley coal; 85 to 99% for the Powhattan No. 4 coal; 92 to 95% for the Warwick coal; 92 to 98% for the Weldon coal; and 89 to 93% for the Fox coal. The corresponding final pyrite changes were 0.62% to 0.38%, 0.44% to 0.04%, 0.09% to 0.06%, 0.47% to 0.15%, and 0.37% to 0.26%, respectively. In a similar manner, grinding the Lucas coal to 150 mesh x 0 increased removal by 9% to 94% and reduced the final pyritic sulfur content from 0.21% to 0.08%. Thus, grinding the coals to 150 or 200 mesh x 0 allows a much faster rate of reaction, and equal or increased pyrite removal is observed in all cases.

Since kinetic data were being generated with the final 20 coals treated in this survey, the reaction times were held at 23 hours except in special cases. However, based on the final pyritic sulfur content obtained after 13 hrs in the trial runs, the coal was further ground to either 150 or 200 mesh x 0 in order to ensure greater than 90% pyritic sulfur removal. Using this technique, nine of the 20 coals were ground to 150 mesh x 0 and six of the coals to 200 mesh x 0 in order to achieve this goal. In addition, it was found on the basis of samples taken from the reactor after 13 hours, that pyritic sulfur removal was greater than 90% for eleven coals, greater than 80% for seven coals, and indeterminate for two other coals (due to poor samples).

The data were examined by geographic region for the amount of fineness required in order to achieve greater than 90% pyrite removal. It was determined that, while it was not necessary to grind any Western coal finer than the standard 100 mesh x 0 to obtain a low final pyritic content, 50-60% of the coals from both the Interior and Appalachian coal basins needed to be ground finer than the standard 100 mesh x 0. Because of the limited number of samples from the Interior Basin, no further correlation could be made. However, for coals from the Appalachian Basin, it was found that 75% of the samples from both the Pittsburgh (8 samples) and Kittanning (4 samples) seams, 33% of the three Freeport samples, and 50%

of the two Sewickley samples needed size reduction. Examination of the Appalachian coal by stratigraphic groups showed that 70% of the 10 samples from the oldest Monongahela series including the Sewickley (Meigs Creek No. 9) and Pittsburgh seams required further grinding. In the Allegheny Series including the Freeport and Kittanning seams, 60% of the 7 coals needed further size reduction while only 20% (1 sample) of the remaining 6 different seam samples from the youngest Kanawha Group needed to be reduced further. Thus, it appears that in order to obtain 90-100% pyrite removal, 50-60% of the coals from the Eastern part of the U.S. must be ground finer than 100 mesh (149μ). For Appalachian coals this requirement increases for the older stratigraphic groups. Furthermore, it was found that additional comminution of the coal increased the rate of pyrite removal substantially, so that in all but two cases the target of 90% removal was achieved in 13 hrs or less instead of 23 hours.

The effect of coal particle size on the ultimate amount and rate of pyrite removal has emerged as a very important process variable. Because the present program was oriented toward complete pyrite removal, a detailed study of particle size was not made. Thus, while it appears that 50-60% of the Eastern coals must be ground finer than 100 mesh (149μ) for complete removal (under the standard set of conditions utilized here), it is not known whether or not >90% removal could be obtained in certain cases if the coal was reduced to only 80 mesh, 50 mesh or larger sizes. In addition, the exact effect of coal fineness on the rate of pyrite removal has not been established. It is thus recommended that further work include substantial studies on the effect of coal particle size on the extent and rate of pyrite removal.

Although the precision of the results of this survey has been excellent, Run No. 2 on the Eagle No. 2 coal and Run No. 3 on the Jane coal are exceptions; the former shows lower than expected final pyrite, and the latter shows higher than expected final pyrite. The data and circumstances surrounding these experiments have been carefully examined and checked and no systematic reasons can be found for these discrepancies. The high standard deviation for Runs 1 and 3 on the Camp Nos. 1 and 2 coal led to the discovery that the temperature controls were maintaining all the leach solutions 2-6°C below reflux; the spread in pyrite removals appears to parallel these differences. Run No. 4, carefully held at reflux, resulted in much higher removal. Although the results of the second set of 20 coals are much more precise than the initial set, a close examination of the results listed in Appendices C and D also shows that the spread between triplicate pyritic sulfur values is often of the order of 0.1-0.2% w/w. Thus, duplicate or triplicate runs or determinations are necessary in order to obtain results that can be treated with a relatively high degree of confidence.

4.3.3 Rate of Pyritic Sulfur Removal

The rate of pyrite removal was also followed for the 20 coals sampled for this part of the survey by withdrawing slurry samples periodically from the reactor. As discussed in Section 4.3.1.2, some difficulty was encountered in obtaining representative samples from the reactor. The principal problem was that the boiling and stirred leach solution still acted as a float-sink medium for the coals. This was especially true for the high ash ROM samples used in this survey. Thus, 15 coals were leached with varying degrees of success before a satisfactory method of sampling was developed. The method (Section 4.3.1.2 and Method D in Table 9) consisted of using an aluminum tube that was rapidly inserted along the vertical axis of the reactor and was closed off when it reached the bottom. Assuming a uniform horizontal distribution, a representative slice was therefore taken along the non-uniform vertical axis. When interpreting the data in Tables 9 and 10, the data obtained by Methods A, B and C from samples taken during the first six hours of leaching should be regarded with some suspicion.

The rate data are summarized in Table 9 in terms of % pyritic sulfur removal, and in Table 10 in terms of pyritic sulfur content. The data indicate that for all coals tested, the major portion of the pyrite is removed in six to seven hours with the average removal being 85 ±6% (median 86%). After six to seven hours, pyrite removal slows down substantially; 90-95% removal is attained in 10-23 hours. Although significant reaction amounting to more than 10% occurred for the Isabella, Bird No. 3, and Meigs mines during the 12-23 hour interval, eleven mines had

Table 9

PYRITIC SULFUR REMOVAL AS A FUNCTION OF TIME IN PERCENT[a,b,c]

Mine	Seam	Method[d]	Mesh[e]	Initial % Pyritic Sulfur	Time, Hours											
					0.5	1.0	2.0	3.0	5.0	6.0	7.0	8.0	9.0	10.0	12.0	13.0	23.0
Muskingum	Meigs Creek No. 9	B	100	3.65	(51)[a]	(57)[a]		34	73*[b]	75*[b]		80				86	93
Powhattan No. 4	Pittsburgh No. 8	A	100	2.75	--[c]	--		--	--				--	69	72		84
		D[f]	200		58	68	76		82	85			(74)			92	97
Isabella	Pittsburgh	B	100	1.07	--	--		--	54*			64				79	96
Mathies	Pittsburgh	A	150	1.05	(67)			(68)	74			77				90	95
Williams	Pittsburgh	C	100	2.23	(58)	(72)		(87)	(92)			94		95	90		87
		D[f]	150		55	68	77	87	87	90				87		94	96
Robinson Run	Pittsburgh	B	150	2.89	--	--		--	42*	--	--					--	97
Shoemaker	Pittsburgh	C	100	2.19	54	69		81	85		88	89			92		89
		D[f]	150		51	66	76		87							95	98
Delmont	Upper Freeport	B	200	4.56	--	--		--	--	--	--					--	95
Marion	Upper Freeport	A	100	0.90	(57)			80	88			90				96	96
Lucas	Middle Kittanning	A	100	1.42	(74)			85	85			92				94	85
		D[f]	150			46		80		87		87				99	N.A.
Bird No. 3	Lower Kittanning	B	150	2.87	--	--		--	63*	--	77	81				82	95
Fox	Lower Kittanning	D	200	3.09		51	70	77		83		87				91	N.A.
Martinka	Lower Kittanning	D	100	1.42	42*	45*		63	68			73			83		92
Meiggs	Clarion 4A	A	100	2.19	42*	58*		77*	74				79	82		84	92
Dean	Dean	D	150	2.62	12	34		59	69		75					84	94
Kopperston No. 2	Campbell Creek	D	100	0.47	66	74		87		89		91				91	
Harris Nos. 1&2	Eagle & No. 2 Gas	D	100	0.49	51	73		84	83		90				92		94
North River	Corona	D	100	1.42	58	74		77	80			85			87		90
Homestead	No. 11	D	100	3.11	49	71	77		83	81	83					85	93
Ken	No. 9	B&C	100	2.85	--	--	83		88	88	91						90
Star	No. 9	B	150	2.66	43		67	88	84	89	91			93	93		91
				Median Range	53 12-74	68 34-74	76 67-83	78 34-87	82 42-88	87 75-90	87 77-91	87 64-94		87 69-95	90 72-93	90 79-99	94 84-97

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[a] Values in parenthesies are suspected of being high due to lack of ferrous ion accumulation and known deficiencies in the method of sampling.

[b] The precision of the starred values is poor.

[c] A dash indicates that the value was not included due to extremely poor precision or illogical analysis (e.g., gain).

[d] See Section 4.3.1.2, p. 24 for exact details. The slurry sample was withdrawn from the bottom of the reactor in Methods A & B. In Methods C & D, a thief technique was used.

[e] Top size of coal.

[f] Results are from a single repeat experiment.

Table 10

PYRITIC SULFUR REMOVAL AS A FUNCTION OF TIME-% W/W PYRITIC SULFUR^{a,b,c}

Mine	Seam	Method^d	Mesh^e	Initial % Pyritic Sulfur	Time, Hours												
					0.5	1.0	2.0	3.0	5.0	6.0	7.0	8.0	9.0	10.0	12.0	13.0	23.0
Muskingum	Meigs Creek No. 9	B	100	3.65	(1.80)^a	(1.58)^a		1.24	0.99*^{b}	0.90*^{b}		0.72				0.52	0.24
Powhattan No. 4	Pittsburgh No. 8	A	100	2.75	(1.20)	(1.10)		--^{b}	--^{b}				--^{b}	0.86	0.78		0.44
		D^f	200		1.16	0.87	0.67		0.50	0.41			0.72			0.23	0.08
Isabella	Pittsburgh	B	100	1.07	--	--		--	0.49*			0.39				0.23	0.04
Mathies	Pittsburgh	A	150	1.05	(0.41)			(0.34)	0.27			0.24				0.10	0.05
Williams	Pittsburgh	C	100	2.23	(0.93)	(0.63)		(0.30)	(0.18)			0.14		0.12	0.22		0.29
		D^f	150		1.00	0.72	0.52	0.30	0.28	0.26				0.28		0.14	0.10
Robinson Run	Pittsburgh	B	150	2.89	--	--		--	1.67*	--	--					--	0.08
Shoemaker	Pittsburgh	C	100	2.19	1.01	0.67		0.42	0.33		0.27	0.24			0.18		0.46
		D^f	150		1.08	0.75	0.52		0.29	0.27						0.12	0.04
Delmont	Upper Freeport	B	200	4.56	--			--	--	--	--					--	0.21
Marion	Upper Freeport	A	100	0.90	(0.39)			0.18	0.11			0.09				0.04	0.04
Lucas	Middle Kittanning	A	100	1.42	(0.37)			0.21	0.21			0.12				0.08	0.21
		D^f	150			0.76		0.29		0.18		0.19				0.02	N.A.
Bird No. 3	Lower Kittanning	B	150	2.87	--	--		--	1.07*	--	0.67	0.54				0.51	0.13
Fox	Lower Kittanning	D	200	3.09		1.51	0.92	0.70		0.53		0.40				0.28	N.A.
Martinka	Lower Kittanning	D	100	1.42	0.83*	0.78*		0.53	0.46			0.39			0.24		0.12
Meiggs	Clarion 4A	A	100	2.19	1.26*	0.92*		0.72*	0.56				0.47	0.40		0.34	0.17
Dean	Dean	D	150	2.62	2.30	1.74		1.08	0.82		0.66					0.42	0.17
Kopperston No. 2	Campbell Creek	D	100	0.47	0.16	0.12		0.06		0.05		0.04				0.04	N.A.
Harris No. 1 & 2	Eagle & No. 2 Gas	D	100	0.49	0.24	0.13		0.08	0.06		0.05				0.04		0.03
North River	Corona	D	100	1.42	0.60	0.37		0.33	0.29			0.22			0.18		0.14
Homestead	No. 11	D	100	3.11	1.58	0.90	0.73		0.52	0.58	0.52					0.48	0.22
Ken	No. 9	B&C	100	2.85	--	--			0.33	0.35	0.27						0.28
Star	No. 9	B	150	2.60	1.47	0.87	0.48	0.56	0.42	0.29	0.24			0.18	0.18		0.24

a) Values in parenthesis are suspected of being high due to lack of ferrous in accumulation and known deficiencies in the method of sampling.

b) The precision of the starred values is poor.

c) A dash indicates that the value was not included due to extremely poor precision or illogical analysis (e.g., gain).

d) See Section 4.3.1.2, page 24 for exact details. The slurry sample was withdrawn from the bottom of the reactor in Methods A & B. In Methods C and D, a thief technique was used.

e) Top size of coal in mesh.

f) Results are from a single repeat experiment.

insignificant removals of 5% or less and six of these mines showed zero or negative removal in at least one set of runs. In respect to the remaining mines, one was leached for only 13 hours, and no 13-hour samples were taken in two cases. Thus, it appears that a 23-hour reaction time should be considered an upper limit for leaching and that, depending on the coal, 85-95% removal can be achieved in 6-13 hours.

The data for leaching times below six hours is not nearly as easy to interpret because of individual coal variations and because the problems with sampling are most evident when the pyrite content is high. This can readily be seen for the Muskingum, Powhattan No. 4, Mathies, Williams, Shoemaker, Marion, Lucàs and Fox coals, for which as long as 13 hours was necessary for the ferrous ion build-up in solution to account for the apparent pyrite decrease, assuming a sulfate/sulfur ratio of 1:5 (Figure 1). These values, which are in parentheses in Tables 9 and 10, were identified by checking the ratio of total ferrous ion present to the amount of ferrous ion expected for the measured pyritic sulfur decrease (see Section 4.3.4 and Table 13 for details). A value less than one indicates that the measured pyritic sulfur removal obviously is in error on the low side. However, a value greater than one may also be in error due to a low measured pyritic sulfur coupled with a high degree of ferric ion reactivity with the coal. Since this reactivity with the coal appears to be nonlinear with time, there is no known adequate way to determine the extent of this error.

In spite of these problems, a substantial amount of information about the pyrite removal in the early stages of the leaching has been obtained. Median removal values have been determined from the data in Table 9 and were found to be 53% in 0.5 hours, 68% in 1.0 hour, 78% in 3.0 hours, and 87% in 6.0 hours. The range of values was substantial: 12-74% at 0.5 hour, decreasing to 34-74% at 1.0 hour and closing further to 75-90% in 6.0 hours. Although the main reason for these variations may be due to sampling problems, it is likely that they represent significant individual differences between coals.

The median pyritic sulfur removal values in Table 9 are plotted as a function of time in Figure 3. Note that, except for a small amount of

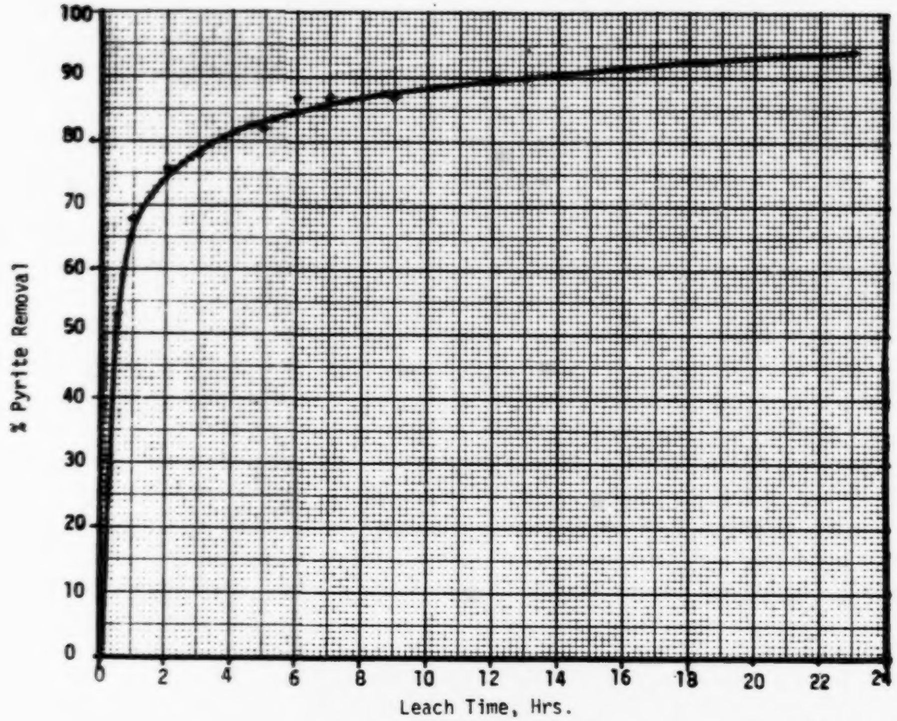

Figure 3. Pyrite Removal as a Function of Time

scatter in the 4-8 hour region, a smooth line can be drawn through all the points. This is an indication that, despite the wide range of removal rates, the kinetic expression is the same order in pyrite, ferrous, and ferric ion concentration in all cases. The peculiar characteristics of the coal, such as pore structure, size distribution of pyrite, etc., may thus be primary factors affecting the rate constant, causing the removal curve for a particular coal to fall either above or below that of Figure 3. Since this is potentially a very significant area in terms of predictions of the applicability of the Meyers Process, it is important that these data be thoroughly examined at a future date for the purpose of fitting a rate expression to these results.

4.3.4 Heat Content Changes and Ferric Ion Consumption

The data in Table 11 presents the results of ferric sulfate extraction of pyritic sulfur from coals in terms of changes in heat content of the coals, and suggests a relationship between this effect and excess ferric

Table 11

SUMMARY OF HEAT CONTENT CHANGES AND EXCESS FERRIC ION CONSUMPTION[a]

Coal Mine	Seam	Dry Basis, btu/lb				Dry Mineral Matter Free Basis, btu/lb				mM Excess Ferric Ion	mM/g Excess Ferric Ion	$\frac{\text{Total Fe}^{++}\text{ Expt.}}{\text{Total Fe}^{++}\text{ Calc.}}$[b]
		Initial	Final	Changes btu/lb	Changes % w/w	Initial	Final	Changes btu/lb	Changes % w/w			
Warwick	Sewickley	8612	9365	+ 753	+ 8.7	15381	15184	- 197	-1.3	134	1.36	2.31
Muskingum	Meigs Creek No. 9	11014	11578	+ 564	+ 5.1	14608	14106	- 502	-3.4	242	2.42	1.45
Egypt Valley No. 21	Pittsburgh No. 8	10594	11506	+ 912	+ 8.6	14851	14554	- 297	-2.0	86	0.86	1.20
Powhattan No. 4	Pittsburgh No. 8	8603	9480	+ 877	+10.2	14573	14607	+ 34	+0.2	121	1.21	1.33
Isabella	Pittsburgh	8216	9312	+1096	+13.3	15197	15199	+ 2	0	105	1.05	1.79
Mathies	Pittsburgh	8154	9024	+ 870	+10.7	14715	14925	+ 210	+1.4	179	1.79	3.04
Williams	Pittsburgh	13013	13587	+ 574	+ 4.4	15309	15142	- 167	-1.1	124	1.24	1.40
Humphrey No. 7	Pittsburgh	13631	13949	+ 318	+ 2.3	15356	15137	- 219	-1.4	98	1.00	1.43
Robinson Run	Pittsburgh	12962	13764	+ 802	+ 6.2	15321	15078	- 243	-1.6	120	1.20	1.27
Shoemaker	Pittsburgh	9495	10156	+ 661	+ 7.0	15049	14841	- 208	-1.4	194	1.94	1.71
Delmont	Upper Freeport	11012	12108	+1096	+10.0	15842	15582	- 260	-1.6	93	0.93	1.16
Marion	Upper Freeport	11046	11720	+ 674	+ 6.1	15517	15539	+ 21	+0.1	47	0.47	1.35
Jane	Lower Freeport	11932	12392	+ 460	+ 3.9	15682	15440	- 242	-1.5	61	0.62	0.79
Lucas	Middle Kittanning	13451	13884	+ 433	+ 3.2	14902	14930	+ 28	+0.2	143	1.43	1.74
Bird No. 3	Lower Kittanning	10551	11500	+ 949	+ 9.0	15835	15601	- 234	-1.5	92	0.92	1.21
Fox	Lower Kittanning	12973	13174	+ 201	+ 1.5	15347	14775	- 572	-3.7	76	0.72	0.89
Martinka	Lower Kittanning	7552	8138	+ 586	+ 7.8	(16447)[d]	15373	-1074	(-6.5)	98	0.98	1.48
Meigs	Clarion 4A	10246	11063	+ 317	+ 8.0	14503	14250	- 253	-1.7	295	2.95	1.92
Dean	Dean	12107	12663	+ 556	+ 4.6	15047	14932	- 115	-0.8	198	1.98	1.51
No. 1	Mason	13054	13341	+ 287	+ 2.2	14997	14743	- 254	-1.7	165	1.69	1.90
Kopperston No. 2	Campbell Creek	10957	11340	+ 383	+ 3.5	(16300)	15687	- 613	(-3.8)	67	0.67	1.97
Harris Nos. 1 & 2	Eagle & No. 2 Gas	12414	12556	+ 142	+ 1.1	15585	15302	- 283	-1.8	112	1.12	2.53
North River	Corona	7693	8323	+ 630	+ 8.2	(16613)	15550	-1063	(-6.4)	97	0.97	1.48
Orient No. 6	Herrin No. 6	11163	11034	- 129	- 1.2	14814	13898	- 916	-6.2	478	4.77	4.03
Homestead	No. 11	11935	12266	+ 331	+ 2.8	14686	14072	- 614	-4.2	570	5.70	2.24
Eagle No. 2	Illinois No. 5	10566	11401	+ 835	+ 7.9	14994	14579	- 415	-2.8	177	1.83	1.47
Camp Nos. 1 & 2	No. 9 (W. Kentucky)	11103	11740	+ 635	+ 5.7	14552	14238	- 314	-2.2	116	1.20	1.34
Ken	No. 9	12099	12689	+ 590	+ 4.9	14614	14209	- 405	-2.8	392	3.92	1.96
Star	No. 9	12308	12650	+ 342	+ 2.8	14620	14006	- 614	-4.2	785	7.85	3.09
Weldon	Des Moines No. 1	11760	12493	+ 733	+ 6.2	14331	13467	- 864	-6.0	981	11.31	1.56
Edna	Wadge	12246	12201	- 45	- 0.4	13602	13186	- 416	-3.1	515	5.33	--c
Navajo[e]	Nos. 6, 7, 8	10050	10353	+ 303	+ 3.0	13849	12908	- 638	-4.8	659	6.66	--c
Belle Ayr	Roland-Smith	12034	11520	- 514	- 4.3	13111	11958	-1153	-8.8	974	12.04	--c
Colstrip	Rosebud	11591	11321	- 270	- 2.3	13065	11993	-1072	-8.2	1520	19.09	--c

a) These values are the average of replicate 23-hour runs, except where noted.

b) The calculated values are based on a sulfate:sulfur ratio of 1:5.

c) These values have not been calculated because the low initial pyrite makes them meaningless.

d) Values in parenthesis are questionable due to high correction factors.

e) Run No. 4.

ion consumption. Because pyrite removal is in effect the removal of low btu "ash" (2995 btu/lb), its removal in most cases has more than compensated for any oxidation of the coal matrix. Thus, with the exception of the Western coals and one Western Interior Basin coal, heat content increases of 1.1-13.3% were observed. The Western coals, with low initial pyrite (0.14-0.34% w/w) and a high order of reactivity with ferric ion, had heat content changes of +3.0 to -4.3%.

Although dry btu determinations are useful for those interested in shipping and using coal, a true picture of the effect of ferric ion oxidation of the organic coal matrix and its relationship to excess ferric ion consumption can only be obtained by examining the dry mineral matter free heat contents. These values (also listed in Table 11) show a heat content loss of 3.1 to 8.8% for the Western coals, 2.0 to 6.0% loss for the Eastern and Western Interior Basin coals, and a +1.4 to -3.7% change for the Appalachian Basin coals.

The heat content changes for the Martinka, Kopperston and North River mines are anomalous in that all three have abnormally high untreated dry-mineral-matter-free heat contents of 16,300-16,600 btu/lb which dropped substantially after treatment to the area normal for other coals, resulting in calculated heat content losses of 600-1100 btu/lb. The excess ferric ion that reacted with 100 g of these coals was only 67-98 mM, which is entirely inconsistent with the 1000-1500 mM ferric ion required for a similar loss for the Belle Ayr and Colstrip coals. Because these coals have an exceptionally high ash content, these errors may be due to the assumption used in the dry-mineral-matter-free calculation. In addition, sample calculations have shown that the dry ash free (daf) heat content becomes very sensitive to small changes in analytical values when the ash content of the coal is >40%. For these reasons, these results are considered suspect and are indicated by parentheses in Table 11. These data are therefore not included in the following calculations.

The differences in dry-mineral-matter-free heat content loss were averaged for all three groups of coals (Table 12). The Appalachian coals averaged a loss of 172 ±185 btu/lb or 1 ±1.2%; the Eastern Interior Basin coals, 592 ±237 btu/lb or 4 ±1.5%; and the Western coals, 896 ±331 btu/lb or 7 ±2.6%. These values were found to be mathematically significant by the t test at the 99% level in all three cases, assuming that the method of calculation did not introduce any systematic error(7,8). Thus, in view of experimental uncertainties and calculation assumptions, heat content loss for the Appalachian coals must be considered nil; for the Interior Basin coals, small; and for the Western coals, significant.

The extent of reaction of the ferric ion with the coal matrix is illustrated by examining excess ferric ion consumption. Ferric ion consumption was calculated by subtracting from the total ferrous ion produced the amount of ferrous ion that should have been produced by pyrite removal, assuming the reaction chemistry of Figure 1 and dividing by the actual amount of coal present (since the ferric ion can attack both the organic and ash contents of the coal). When the values are calculated on a dry-mineral-matter-free basis, the scatter increases substantially.

Table 12

AVERAGE HEAT CONTENT LOSSES AND FERRIC ION CONSUMPTION

Coal Basin	Dry Mineral Matter Free Heat Content, btu/lb			Excess Ferric Ion Consumption	
	Average Initial	Average Loss	Heat Content Loss Per % Loss	Average mM/g	mM/g Per % Heat Content Loss
Appalachian	15166±426	172±185	172	1.3±0.6	1.3
Interior	14658±208	592±232	148	5.2±3.5	1.3
Western	13406±382	896±331	128	10.8±6.3	1.5
			149±22[a]		1.4±0.1[a]

[a] Average value for all three coal basins

These calculations show that the coals fall into three distinct classes, with the Appalachian Coal Basin coal consuming 0.47-2.95 mM/g excess ferric ion, the Interior Coal Basin coal 1.20-11.31 mM/g excess ferric ion and the Western coals 5.33-19.09 mM/g excess ferric ion. The corresponding averages are 1.3, 5.2 and 10.8 mM/g, respectively. In general, the results follow the degree of metamorphism of these coals. The Western coals have low rank and an open pore structure, which provides an abundance of active sites for reaction. The Eastern Interior Basin coals have a higher rank but still have an open pore structure that allows substantial reaction, while the Appalachian Basin coals, though of similar rank, have the most closed pore structure and as a result show very little reaction with the ferric ion.

The data were examined further to establish a relationship between heat content loss and excess ferric ion consumption. These results, tabulated in Table 12, indicate that 0.94 ±0.12 mM/g ferric ion is consumed for every 100 btu/lb loss in heat content.

4.3.5 Ferric Ion Consumption as a Function of Time

The rate of ferric ion consumption was also followed as a function of time, both as an independent check on the pyrite removal values and to determine whether the ferric ion reactivity with coal is linear as a function of time. Previous work(1,2,3) has shown that ferric ion reacts with pyrite according to Eq. 1:

$$FeS_2 + 4.6\ Fe_2\ (SO_4)_3 + 4.8\ H_2O \rightarrow 10.2\ FeSO_4 + 4.8\ H_2SO_4 + 0.8S \qquad (1)$$

to produce 10.2 mM ferrous ion per mM of pyrite (or 5.1 mM ferrous ion per mM pyritic sulfur) and a sulfate/sulfur ratio of 1.5. Assuming this stoichiometry, the mM/g coal excess ferric ion consumption (i.e., the amount of reaction of ferric ion with the coal) can be calculated at any time, t_x, if the actual pyrite and ferrous ion concentrations are known at that time. The calculation is shown in Eq. 2 and values of excess ferric ion are listed as mM/g in Table 13.

$$\begin{matrix}\text{mM/g Coal Excess Ferric} \\ \text{Ion Consumption}\end{matrix} = \begin{matrix}\text{Total Reaction of} \\ \text{Ferric Ion with Coal}\end{matrix} =$$

$$\text{mM/g Coal Ferrous Ion} - \begin{matrix}\text{mM/g Coal Ferrous Ion Generated} \\ \text{by Pyritic Sulfur Removal}\end{matrix} \qquad (2)$$

These values can then be used to calculate the ratio shown in Eq. 3 and tabulated in Column 5 of Table 13.

$$\text{Ratio} = \begin{matrix}\text{Actual Ferrous Ion} \\ \text{Present in mM/g Coal}\end{matrix} \Big/ \begin{matrix}\text{Ferrous Ion Generated by Pyrite} \\ \text{Removal in mM/g Coal}\end{matrix} \qquad (3)$$

The value for Eq. 2 must be positive, and the value for Eq. 3 must be 1.0 or greater by definition. It should be noted, however, from the data shown in Table 13, that several negative values for Eq. 2 were obtained, indicating that the input data for either ferrous ion or pyrite concentration were incorrect. As a result of this finding, both the means of sampling and the analysis of both leach solution and coal were examined for possible error. This examination indicated that sampling error was clearly the cause, since all other methods were standard and tested procedures. This problem and its solution is documented in Sections 4.3.1.2 and 4.3.3 and will not be further discussed in this section.

Table 13

FERRIC ION CONSUMPTION AS A FUNCTION OF TIME[a]

Mine	Seam	Sampling[b] Method	Mesh[c]	Excess Ferric Ion[d,e]	Time, Hours												
					0.5	1.0	2.0	3.0	5.0	6.0	7.0	8.0	9.0	10.0	12.0	13.0	23.0
Muskingum	Meigs Creek No. 9	B	100	mM/g	-0.55	-0.13		0.55	0.41	1.25	1.49					1.94	2.42
				Ratio	0.81	0.96		1.14	1.09	1.29	1.32					1.39	1.45
Powhattan No. 4	Pittsburgh No. 8	A	100	mM/g	-0.94	-0.68		-0.25	-0.05				-0.32	0.88		1.17	1.21
				Ratio	0.62	0.74		0.91	0.98				0.92	1.29		1.37	1.33
		D	200	mM/g	0.56	1.03	1.33		2.56								3.65
				Ratio	-1.22	1.34	1.40		1.71								1.88
Isabella	Pittsburgh	B	100	mM/g	1.58	1.44		0.95	0.87			0.83					1.05
				Ratio	-1.32	-4.02		2.57	1.89			1.77					1.79
Mathies	Pittsburgh	A	150	mM/g	-0.14	0.45		0.58	0.75							0.82	1.79
				Ratio	0.86	1.40		1.47	1.58							1.54	3.04
Williams	Pittsburgh	C	100	mM/g	-0.77	-0.75		-0.49	-0.20			-0.05		0.15	0.75		1.24
				Ratio	0.63	0.70		0.84	0.94			0.98		1.04	1.24		1.40
		D	150	mM/g	0.86	1.25	1.69		2.36								3.11
				Ratio	1.45	1.52	1.62		1.76								1.92
Robinson Run	Pittsburgh	B	150	mM/g	2.93	5.97		3.21	2.20	2.14	1.15					1.21	1.20
				Ratio	-2.61	-0.93		5.12	2.13	1.99	1.33					1.31	1.27
Shoemaker	Pittsburgh	C	100	mM/g	-0.08	-0.33		0.09	0.34		0.63	1.07			1.32		1.94
				Ratio	0.96	0.86		1.03	1.12		1.21	1.34			1.41		1.71
		D	150	mM/g	0.87	0.93	1.00		1.77								2.60
				Ratio	1.49	1.41	1.38		1.59								1.76
Delmont	Upper Freeport	B	200	mM/g	3.74	5.52		3.13	2.90	-0.36	1.40					0.67	0.93
				Ratio	-1.04	-1.04		3.94	2.50	0.94	1.33					1.11	1.16
Marion	Upper Freeport	A	100	mM/g	-0.13	0.11		0.12	0.22							0.29	0.47
				Ratio	0.84	1.09		1.10	1.17							1.21	1.35
Lucas	Middle Kittanning	A	100	mM/g	-0.76	-0.30		0.04	0.23							0.59	1.43
				Ratio	0.55	0.84		1.02	1.11							1.28	1.74
		D	150	mM/g	--	1.35		2.35		2.91		3.57				3.69	--
				Ratio	--	2.79		2.31		2.48		2.83				2.66	--
Bird No. 3	Lower Kittanning	B	150	mM/g	2.15	2.61		2.78	0.86	1.72	0.56	0.47				0.72	0.92
				Ratio	-3.67	-8.11		6.83	1.30	1.82	1.16	1.13				1.19	1.21
Fox	Lower Kittanning	D	200	mM/g	--	-1.84	-2.02	-2.04		-1.96		-2.01				-2.19	
				Ratio	--	0.49	0.56	0.58		0.62		0.62				0.61	
Martinka	Lower Kittanning	D	100	mM/g	0.24	0.65		0.80	1.07			1.28			1.20	0.98	
				Ratio	1.26	1.64		1.57	1.70			1.78			1.04	1.48	
Meigs	Clarion 4A	A	100	mM/g	0.43	0.44		1.04	1.30				1.89		2.17	2.58	2.95
				Ratio	1.79	1.72		1.45	1.50				1.69		1.76	1.88	1.92
Dean	Dean	D	150	mM/g	1.71	1.51		1.45	1.64		2.10					1.72	1.88
				Ratio	4.36	2.08		1.59	1.57		1.68					1.49	1.51
Kopperston No. 2	Campbell Creek	D	100	mM/g	0.25	0.50		0.77	0.94			0.88				0.67	--
				Ratio	1.50	1.93		2.18	1.41			2.28				1.97	--
Harris No. 1 & 2	Eagle & No. 2 Gas	D	100	mM/g	0.51	0.52		0.76	0.92						1.16		1.12
				Ratio	2.33	1.90		2.16	2.34		1.07	0.88			2.63		2.53
North River	Corona	D	100	mM/g	0.07	0.17		0.56	0.82		2.53	1.46			0.89		0.97
				Ratio	1.05	1.01		1.32	1.46						1.45		1.48
Homestead	No. 11	D	100	mM/g	0.59	0.35	1.00		1.91	3.39	3.85					5.00	5.32
				Ratio	1.24	1.10	1.16		1.46	1.84	1.94					2.20	2.16
Ken	No. 9	B&C	100	mM/g	--	--		0.56	0.88	1.89	2.20						3.92
				Ratio	--	--		1.15	1.22	1.47	1.54						1.96
Star	No. 9	B	150	mM/g	1.61	1.30		2.72	2.81	3.70	4.17				5.25	6.12	7.85
				Ratio	1.94	1.47		1.68	1.81	2.01	2.11				2.36	2.59	3.09

[a] These values correlate with those in Tables 9 and 10.

[b] See Section 4.3.1.2, p. 24 for exact details. The slurry sample was withdrawn from the bottom of the reactor in Methods A & B. In Methods C & D, a "thief" technique was used.

[c] Top size of coal

[d] mM/g = calculated millimoles of ferric ion that reacted with one gram of coal

[e] Ratio = actual mM of ferric ion that reacted divided by the amount of ferric ion necessary for pyrite removal

Because of the unreliability of much of the sampling data for Sampling Methods A, B, and C, only the results obtained by Method D (Table 13) are noteworthy. Examination of these runs indicates that the mM/g excess ferric ion concentration increases as a function of time in all cases, indicating that reaction with the coal continues as long as ferric ion is present. The data do not have enough precision, however, to conclusively show whether or not the effect is linear. Since the rate of removal of pyrite is a nonlinear reaction(1,3), the variation of the ratio in Eq. 3 was closely examined. A constant ratio would indicate coal reactivity paralleling the rate of pyrite removal. The results indicate that for the Powhattan No. 4, Williams, and Homestead mines the ratio increased; for the Shoemaker, Lucas, Harris No. 1 & 2 and North River mines, there was a slight increase; the Martinka and Kopperston mines showed small changes and the Dean mine showed a drop. Thus, it appears that reactivity with the coal matrix depends to a large extent on the nature of the coal and that this phenomenon should be examined in detail in the future.

4.3.6 Removal of Residual Sulfate

The data presented in Table 14 indicate that substantial sulfate is retained on some coals when a minimal coal wash procedure is used after extraction of pyritic sulfur. The wash procedure consists of three 500 ml hot water rinses of the coal on the filter funnel after filtration of the reaction mixture. This procedure, which was used on many trial runs and the final triplicate runs for Camp Nos. 1 & 2 and Orient No. 6 coals, resulted in sulfate values (sulfur as sulfate, but referred to only as sulfate in the following discussion) ranging from a very acceptable 0.06-0.10% (Jane, Humphrey No. 7 and Colstrip) to a very high 0.45-0.85% (Mathies, Orient No. 6, Eagle No. 2, Belle Ayr, and Edna) with the majority of coals falling in the range of 0.2-0.4% (see Table 14).

It is currently believed that sulfate retained on the treated coals can be reduced or eliminated by one or more of the following methods: (a) control of acidity and iron concentration or form during extraction, (b) selection of optimum filtration temperature, (c) equilibration of the leach solution with the coal as in the thickener section of a process plant, or (d) selection of the appropriate washing parameters. Because detailed evaluation of these processing techniques was not practical during this program, only those approaches involving washing techniques were investigated. Several of these methods have been evaluated under a separate EPA program for bench-scale experimentation (Contract No. 68-02-1336, Reference 3) and have been found to be effective.

Table 14

SULFATE CONTENT OF TREATED COALS[a]

(% w/w)

Mine	Seam	Mesh	% W/W SULFATE			
			Initial	Regular[a,b] 12-14 Hrs.	Minimal[a,b] 12-14 Hrs.	Regular[a,c] 21-23 Hrs.
Warwick	Sewickley	100	0.01	---	0.35	0.14
Muskingum	Meigs Creek No. 9	150	0.06	0.11		0.17
Egypt Valley No.2	Pittsburgh No. 8	100	0.14		0.25	0.11
Powhattan No. 4	Pittsburgh No. 8	100	0.19	0.08		0.12
Isabella	Pittsburgh	100	0.04	0.04		0.01
Mathies	Pittsburgh	150	0.04		0.65	0.10
Williams	Pittsburgh	100	0.04	0.02		0.06
Humphrey No. 7	Pittsburgh	100	0.01		0.10	0.10
Robinson Run	Pittsburgh	150	0.06	0.06		0.00
Shoemaker	Pittsburgh	100	0.05	0.04		0.03
Delmont	Upper Freeport	200	0.08	0.05		0.06
Marion	Upper Freeport	100	0.02		0.40	0.06
Jane	Lower Freeport	100	0.00		0.06	0.06
Lucas	Middle Kittanning	100	0.05		0.23	0.13
Bird No. 3	Lower Kittanning	150	0.05	0.05		0.11
Fox	Lower Kittanning	100	0.05		0.31	0.09
Martinka	Lower Kittanning	100	0.07	0.08		0.08
Meigs	Clarion 4A	100	0.06	0.13		0.14
Dean	Dean	150	0.15		0.22	0.16
No. 1	Mason	100	0.08		0.26	0.09
Kopperston No. 2	Campbell Creek	100	0.03	0.07		0.08
Harris Nos. 1&2	Eagle & No. 2 Gas	100	0.03		0.30	0.06
North River	Corona	100	0.07	0.08		0.09
Orient No. 6	Herrin No. 6	200	0.01	0.17	0.45[d]	0.22
Homestead	No. 11	100	0.10		0.40	0.30
Eagle No. 2	Illinois No. 5	100	0.04	0.18	0.85[d]	0.23
Camp Nos. 1&2	No. 9 (W. Kentucky)	100	0.06		0.42[d]	0.28
Ken	No. 9	100	0.26		0.38	0.26
Star	No. 9	150	0.24		0.42	0.34
Weldon	Des Moines No. 1	100	0.15	0.12	0.31	0.18
Edna	Wadge	100	0.00		0.68	0.49
Navajo	Nos. 6,7,8	100	0.03	0.15 0.12[e]	0.54	
Belle Ayr	Roland-Smith	100	0.00	0.14	0.64	0.85
Colstrip	Rosebud	100	0.00	0.06	0.06	

[a] See text for explanation of procedure.

[b] Most of the data in this column is derived from single analysis trial runs.

[c] The data in this column are derived from the average of the analysis of two or three runs.

[d] 23-hr. run.

[e] 6-hr. run.

Table 15 summarizes sulfate extraction experiments performed on the treated Camp Nos. 1 and 2 coal. Note that both methanol and aqueous methanol are much less effective than water in reducing the sulfate content of the coal, but that the addition of 1% v/v sulfuric acid to aqueous methanol reduces the sulfate to 0.24% w/w. In addition, basic solutions such as 5% w/v sodium carbonate and 10% v/v concentrated ammonium hydroxide in aqueous methanol, and chelating agents such as 3% w/w ethylenediamine tetraacetic acid and 10% w/w tetraethylene tetraamine, are apparently slightly more effective than water in reducing the sulfate level.

Table 16 summarizes a second set of sulfate extraction experiments performed on treated Orient No. 6 coal. With this coal, an additional wash with either water, 0.1-3N sulfuric acid, or 1N oxalic acid for one hour at elevated temperature was effective in reducing the sulfate level from 0.62 to 0.25% w/w or less. Washing with 1N sulfuric acid at 30°C (Expt. 6) was

Table 15

SPECIAL SULFATE REMOVAL EXPERIMENTS
CAMP NOS. 1 AND 2 COAL[a,b]

Experiment	Reagent	Temp., °C	Final % SO_4, w/w
1	H_2O	Reflux	0.19
2	CH_3OH	Reflux	0.33
3	aq.CH_3OH[c]	Reflux	0.49
4	1% H_2SO_4 in aq. CH_3OH[c]	Reflux	0.24
5	5% Na_2CO_3 in aq.CH_3OH[c]	Reflux	0.13
6	10% NH_4OH in aq.CH_3OH[c]	Reflux	0.20
7	3% EDTA in aq. CH_3OH[c]	Reflux	0.13
8	10% Tetraethylene tetraamine in aq. CH_3OH[c]	Reflux	0.11

[a] Initial sulfate retention 0.42% w/w, the ratio of coal to extraction solution was 1:60 w/v

[b] Extraction time of four hours followed by thorough water wash

[c] Methanol:water ratio of 7.3

Table 16

SPECIAL SULFATE REMOVAL EXPERIMENTS, ORIENT NO. 6 COAL[a,b]

Experiment	Reagent	Temp., °C	Final % SO_4, w/w
1	H_2O	∿90	0.25
2	0.1N H_2SO_4	∿80	0.21
3	0.5N H_2SO_4	∿80	0.23
4	1.0N H_2SO_4	∿80	0.19
5	3.0N H_2SO_4	∿80	0.23
6	1.0N H_2SO_4	∿30	0.36
7	1N Oxalic Acid	∿60	0.16

[a] Initial sulfate retention 0.62% w/w, the ratio of coal to extraction solution was 1:20 w/v

[b] Extraction time of one hour followed by thorough hot water wash

not as effective, giving a final sulfate value of 0.36% w/w and indicating that elevated temperature is necessary for more effective sulfate removal. However, since the results of all 7 experiments are from single trials and since the values, with the exception of Experiment 6, are grouped so closely, the remaining six methods (Methods 1, 2, 3, 4, 5 and 7) in Table 16 can be considered equally effective at this point.

Based on the above experimentation, water washing as well as washing with dilute sulfuric acid is capable of removing residual sulfate. Dilute sulfuric acid should be advantageous in those cases where basic iron sulfates are present. Basic solutions or chelating agents, though effective, would introduce unnecessary process expense and should not be considered if the above methods are effective. Therefore, the following standard procedure was adopted for the survey studies in order to ensure, without optimization, a low level of sulfate in the treated coals.

> The extracted coal is slurried with 2 ℓ of 1N sulfuric acid at ∿80°C for 2 hours, filtered and stirred with another 2 ℓ 1N sulfuric acid at ∿80°C for an additional two hours. After

filtration, this procedure is repeated with 2 ℓ water at ∿80°C. If scheduling does not permit the coal to be extracted with toluene immediately, stirring is continued at ∿50°C for an extended period until filtration and extraction can be performed.

The results listed in Table 14 are summarized in Table 17 and show that the final sulfate content can be reduced to 0.06-0.17% w/w for the Appalachian Basin coals, 0.17-0.35% w/w for the Eastern and Western Interior Basin coals, and 0.06-0.85% w/w for the Western coals using this method. The median final sulfate values for 23 hr runs involving the Appalachian and Interior Basin coals were 0.09% and 0.28%, respectively, indicating that sulfate retention is much more pronounced for the Interior Basin coals. Data for 12-14 hr reaction times indicate that reaction time did not significantly affect the final median sulfate content of the Appalachian coals, while the median for the Interior Basin coals is reduced 0.11% to 0.17%. With the Western coals, reaction times of 6-14 hrs were necessary in order to prevent excessive sulfate retention. Thus, given a standard set of working conditions, it can be concluded that sulfate retention depends both on the coal basin in which it is mined and to a certain extent on the coal leaching time.

Table 17

SUMMARY OF TREATED COAL SULFATE CONTENT
(% w/w)

	Median		Average		Low		High	
Coal Basin	Initial[a]	Treated[b]	Initial	Treated	Initial	Treated	Initial	Treated
Appalachian								
a) 23 hrs.	0.05	0.09	0.06	0.09	0.00	0.00	0.19	0.17
b) 12-14 hrs.		0.06		0.07		0.02		0.13
Interior								
a) 23 hrs.	0.09	0.28	0.12	0.26	0.01	0.18	0.26	0.34
b) 12-14 hrs.		0.17[c]		0.16[c]		0.17[c]		0.18[c]
Western								
a) 23 hrs.	0.00	---[d]	0.01	>0.50[d]	0.00	0.49	0.03	0.85
b) 6-14 hrs.		0.13		0.12		0.06		0.15

[a] ROM unleached coal.

[b] Treated coal washed by procedure on page 48 to remove sulfate.

[c] Insufficient data-two runs only.

[d] Three runs only.

In addition to the above conclusions, it should also be kept in mind that, as indicated in Table 14, the amount of sulfate retained appears to depend somewhat on the individual characteristics of the coal. Also, the washing procedure used here, while conforming to the general constraints of the Meyers Process, has not been optimized. In particular, the use of a continuous countercurrent wash or multiple washes may be as effective as the prolonged washes used above. Moreover, a sulfuric acid wash may not be necessary. Thus, for a complete understanding of the problem, several coals should be further investigated in detail in order to determine the minimum conditions necessary for sulfate removal.

4.3.7 Summary of Ash Changes

Table 18 summarizes the ash changes which occurred upon extraction of the coals with ferric sulfate. The expected ash change or loss can be computed from the relative molecular weights and the assumptions that all the pyritic sulfur FeS_2, is converted to iron oxide (Fe_2O_3) in the ashing process at 800°C:

$$\underset{\text{M.W. } 119.85}{FeS_2} + 2.75\ O_2 \longrightarrow \underset{\text{M.W. } 159.70}{0.5\ Fe_2O_3} + 2\ SO_2$$

Thus, 64.00 g of sulfur from FeS_2 is converted to 159.70 x 0.5 or 79.85 g of ferric oxide during the ashing process, which results in 1.25% ash (79.85/64.00) production for every 1.00% pyritic sulfur present. The calculated ash loss can then be computed by multiplying the absolute percent pyritic sulfur removal by 1.25. In all cases, more ash was removed than can be accounted for by pyrite removal alone. In general, excess removal was greatest for the Western coals which averaged 3.9% excess removal, while coals from the Appalachian and Interior Coal Basins had similar excess removals, averaging 2.4 and 2.6%, respectively.

The various coal mines were also examined for correlations by seams and ash content (Table 19). In the Appalachian region, there were no significant differences between the coal seams. In the Interior coal basins, differences occurred between seams; however, these results are not considered significant because of the small number of mines considered. When the coals are examined by ash content, it is clear that excess removal

Table 18

SUMMARY OF ASH CHANGES
(% W/W[a])

Mine	Seam	Initial	Extracted	Change	Calculated Change[b]	Excess
Warwick	Sewickley	40.47	35.32	-5.15	-1.25	-3.90
Muskingum	Meigs Creek No. 9	21.68	16.05	-5.63	-4.26	-1.37
Egypt Valley No. 21	Pittsburgh No. 8	25.29	18.86	-6.43	-5.56	-0.87
Powhattan No. 4	Pittsburgh No. 8	37.17	32.13	-5.04	-2.89	-2.15
Isabella	Pittsburgh	42.22	35.72	-6.50	-1.29	-5.21
Mathies	Pittsburgh	41.01	36.43	-4.58	-1.25	-3.33
Williams	Pittsburgh	13.18	9.16	-4.02	-2.43	-1.59
Humphrey No. 7	Pittsburgh	9.88	6.97	-2.91	-1.81	-1.10
Robinson Run	Pittsburgh	13.36	7.63	-5.73	-2.43	-3.31
Shoemaker	Pittsburgh	33.48	28.87	-4.61	-2.16	-2.45
Delmont	Upper Freeport	27.18	20.44	-6.74	-5.44	-1.30
Marion	Upper Freeport	26.40	22.61	-3.79	-1.08	-2.72
Jane	Lower Freeport	21.75	17.99	-3.76	-1.63	-2.13
Lucas	Middle Kittanning	8.68	6.32	-2.31	-1.51	-0.80
Bird No. 3	Lower Kittanning	30.23	24.17	-6.06	-3.43	-2.63
Fox	Lower Kittanning	13.55	9.72	-3.83	-3.40	-0.43
Martinka	Lower Kittanning	49.25	43.46	-5.79	-1.63	-4.17
Meigs	Clarion 4A	26.53	20.38	-6.15	-2.53	-3.63
Dean	Dean	17.28	13.66	-3.62	-3.06	-0.56
No. 1	Mason	11.39	8.50	-2.89	-2.21	-0.68
Kopperston No. 2	Campbell Creek	30.15	25.53	-4.62	-0.54	-4.08
Harris Nos. 1&2	Eagle & No. 2 Gas	18.63	16.46	-2.17	-0.58	-1.60
North River	Corona	49.28	42.84	-6.44	-1.60	-4.84
Orient No. 6	Herrin No. 6	22.51	18.85	-3.66	-1.23	-2.43
Homestead	No. 11	16.56	11.50	-5.06	-3.61	-1.45
Eagle No. 2	Illinois No. 5	26.53	19.80	-6.73	-2.96	-3.77
Camp Nos. 1&2	No. 9 (W. Kentucky)	21.13	15.77	-5.36	-2.73	-2.63
Ken	No. 9	15.08	9.44	-5.64	-3.21	-2.43
Star	No. 9	13.90	8.58	-5.32	-2.95	-2.37
Weldon	Des Moines No. 1	15.74	6.43	-9.31	-5.96	-3.35
Edna	Wadge	9.13	6.77	-2.36	-0.10	-2.26
Navajo	Nos. 6,7,8	25.29	20.53	-4.76	-0.30	-4.46
Belle Ayr	Roland-Smith	7.55	3.37	-4.18	-0.24	-3.94
Colstrip	Rosebud	10.38	5.17	-5.21	-0.35	-4.86

[a] All values in the Table are in % W/W and are an average of two or more values based on Runs 1 and 2 in Appendix D and Runs 1, 2 and 3 in Reference 2.

[b] Based on the removal of pyrite, FeS_2.

Table 19

AVERAGE EXCESS ASH REMOVALS (% W/W)

Region		Seam[a]		Ash Content[b]	
Appalachian (23)[c] —	2.4[d]	Sewickley (2)[c]	2.6[d]	Low (7)[c]	1.2[d]
		Pittsburgh (7)	2.7		
		Freeport (3)	2.4	Medium (8)	2.1
		Kittanning (5)	2.3	High (8)	3.7
		Others (5)	2.4		
Eastern & Western Interior (7) —	2.6	Herrin No. 6 (2)	1.9	Low (4)	2.4
		Illinois No. 5 (4)	2.8	Medium (3)	2.9
		Des Moines No. 1 (1)	3.3	High (0)	---
Western (4) —	3.9			Low (3)	3.7
				Medium (1)	4.5
				High (0)	---

[a] Seam correlations: 1) Sewickley = Meigs Creek No. 9; 2) Herrin No. 6 = No. 11; 3) Illinois No. 5 = No. 9.

[b] Low Ash, 0-15%; Medium Ash, 15-25%; High Ash, >25%.

[c] Number of mines in sample.

[d] Average ash loss in weight %.

increases with increasing ash content. This is most apparent with the Appalachian coals, where high ash coals (>25% w/w) have more than three times the excess removal of low ash coals (0-15% w/w).

Since the aqueous extraction solution is both acidic and oxidizing, inorganic materials in the ash could be brought into solution by either an acidic or oxidizing attack. However, the most likely mechanism of solution probably is dissolution of basic inorganic compounds by the sulfuric acid that is present in solution (Figure 1). Since acid soluble compounds of sodium, potassium, magnesium and iron, such as oxides and carbonates, can be major constituents of coal ash, they could easily account for the excess ash removal. However, since research has thus far not accurately resolved these questions, additional experimentation should be performed in order to establish purification requirements for recycled ferric sulfate streams. In addition, the use of "cleaned" coal which normally has 40-70% less ash than ROM coal would substantially reduce any purification requirements. Operation of a continuous large-scale (pilot) facility may be required to completely clarify potential problems in this area.

4.3.8 Organic Sulfur Changes

After several coals had been extracted, the results seemed to indicate that the treated coal apparently had a higher organic sulfur content than the starting coal. Although organic sulfur increases of 0.01-0.14% w/w were attributable to ash removal, these did not account for all of the apparent increases. However, the organic sulfur value is the least accurate of all sulfur analyses because it is not determined directly, but by subtracting the amount of pyritic and sulfate sulfur from the total sulfur. For this reason, the organic sulfur value contains resultant errors from all three analyses. Thus, according to ASTM Standards(6), duplicate organic sulfur values with spreads of up to 0.4-0.6% w/w can be considered acceptable for analyses done by different operators in different laboratories. The problem is made even more complicated due to the possibility that treating the coal with ferric sulfate solution can introduce a systematic error in the results. Therefore, a thorough statistical analysis was made in order to assess the validity of the indicated results.

All the data were tested for significance by applying the t test, in which the value of t was calculated according to the equation:

$$t = \frac{(\bar{B} - \bar{A})\sqrt{n}}{\sigma_d}$$

where

$\bar{A}$ = average starting organic sulfur,
$\bar{B}$ = the average final organic sulfur,
n = the number of values in each set, and
σ_d = the standard deviation of the difference $\bar{B} - \bar{A}$.

The value of t is then used to determine the level of significance by consulting a standard table of values used for the t distribution(7).

These data, which are summarized in Tables 20 and 21, show that, although no increases are found for Western coals, significant average increases of 0.23 and 0.31% w/w are found for the Appalachian and Interior coals, respectively. Differences between various seams in each region and between these regions themselves were tested and not found to be significant. The chances that the organic sulfur increases for coals in these regions are real were found to be significant at the 99% confidence level.

Table 20
ORGANIC SULFUR DATA

Mine	Seam	Run	Total Rxn. Time	Mesh[a]	ORGANIC SULFUR (% W/W)					Significance Level for Increase[d]			
					Initial	Final	Difference	Calculated Increase[b]	Corrected Difference[c]	>0.0	>0.1	>0.2	>0.4
Warwick	Sewickley	1-3	23	100	0.27 ±.088	0.59 ±.061	+0.32 ±.107	0.02	+0.30 ±.107	95	90	70	
Muskingum	Meigs Creek No. 9	1-2	23	150	2.37 ±.113	2.81 ±.044	+0.44 ±.121	0.14	+0.30 ±.121	80	None	--	--
Egypt Valley No.21	Pittsburgh No. 8	1-3	13-23	100	1.34 ±.026	2.16 ±.182	+0.82 ±.184	0.09	+0.73 ±.185	95	95	95	90
Powhattan No. 4	Pittsburgh No. 8	1-2	23	100	1.36 ±.097	1.48 ±.053	+0.12 ±.111	0.07	+0.05 ±.111	None	--	--	--
Isabella	Pittsburgh	1-2	23	100	0.46 ±.074	0.65 ±.014	+0.19 ±.078	0.03	+0.16 ±.075	80	None	--	--
Matnies	Pittsburgh	1-2	23	150	0.37 ±.068	0.79 ±.041	+0.42 ±.079	0.02	+0.40 ±.079	90	90	80	None
Williams	Pittsburgh	1-2	23	100	1.21 ±.063	1.39 ±.046	+0.18 ±.079	0.05	+0.13 ±.078	70	None	--	--
Humphrey No. 7	Pittsburgh	1-3	23	100	0.98 ±.120	1.25 ±.088	+0.27 ±.148	0.03	+0.24 ±.148	90	70	None	--
Robinson Run	Pittsburgh	1-2	23	150	1.43 ±.193	2.12 ±.014	+0.69 ±.194	0.09	+0.60 ±.194	80	80	70	None
Shoemaker	Pittsburgh	1-2	23	100	1.27 ±.100	1.34 ±.169	+0.07 ±.196	0.06	+0.01 ±.196	None	--	--	--
Delmont	Upper Freeport	1-2	23	200	0.25 ±.051	0.69 ±.125	+0.44 ±.135	0.02	+0.42 ±.135	80	80	70	None
Marion	Upper Freeport	1-2	23	100	0.45 ±.035	0.58 ±.103	+0.13 ±.109	0.02	+0.11 ±.109	None	--	--	--
Jane	Lower Freeport	1-2	12-23	100	0.41 ±.051	0.49 ±.035	+0.08 ±.062	0.02	+0.06 ±.062	None	--	--	--
Lucas	Middle Kittanning	1-2	23	100	0.32 ±.147	0.55 ±.095	+0.23 ±.175	0.01	+0.22 ±.175	None	--	--	--
Bird No. 3	Lower Kittanning	1-2	23	150	0.22 ±.080	0.56 ±.080	+0.34 ±.113	0.01	+0.33 ±.113	80	70	None	--
Fox	Lower Kittanning	1-3	23	100	0.69 ±.044	1.18 ±.206	+0.49 ±.211	0.03	+0.46 ±.211	90	90	80	None
Martinka	Lower Kittanning	1-2	23	100	0.57 ±.025	0.38 ±.021	-0.19 ±.033	0.04	-0.23 ±.033	90	80	None	--
Meigs	Clarion 4A	1-2	23	100	1.48 ±.046	1.63 ±.061	+0.15 ±.076	0.10	+0.05 ±.076	None	--	--	--

Table 20 (Cont'd)

Dean	Dean	1-2	23	150	1.32 ±.091	1.75 ±.033	+0.43 --	0.05	+0.37 ±.097	80	80	70	None
No. 1	Mason	1-3	23	100	1.06 ±.126	1.32 ±.133	+0.26 ±.183	0.03	+0.23 ±.183	70	None	--	--
Kopperston No. 2	Campbell Creek	1-2	13	100	0.41 ±.055	0.49 ±.041	+0.08 --	0.02	+0.06 ±.069	None	--	--	--
Harris Nos. 1&2	Eagle & No. 2 Gas	1-2	23	100	0.48 ±.036	0.67 ±.039	+0.19 --	0.01	+0.18 ±.053	80	70	None	--
North River	Corona	1-2	23	100	0.57 ±.025	0.70 ±.040	+0.13 --	0.04	+0.09 ±.047	70	None	--	--
Orient No. 6	Herrin No. 6	1-3	23	100	0.36 ±.109	0.46 ±.095	+0.10 ±.145	0.01	+0.09 ±.145	None	--	--	--
Homestead	No. 11	1-2	23	100	1.25 ±.051	1.86 ±.116	+0.61 --	0.01	+0.60 ±.127	90	80	80	None
Eagle No. 2	Illinois No. 5	1-3	13-14	100	1.61 ±.156	1.68 ±.065	+0.07 ±.169	0.12	-0.05 ±.169	None	--	--	--
Camp Nos. 1&2	No. 9 (W. Kentucky)	1-3	13	100	1.65 ±.130	1.73 ±.066	+0.08 ±.146	0.09	-0.01 ±.146	None	--	--	--
Ken	No. 9	1-2	23	100	1.72 ±.053	2.24 ±.043	+0.52 --	0.07	+0.45 ±.071	90	90	80	None
Star	No. 9	1-2	23	150	1.50 ±.075	2.06 ±.097	+0.56 --	0.08	+0.48 ±.123	80	80	80	None
Weldon	Des Moines No. 1	1-3	23	100	1.00 ±.069	1.69 ±.161	+0.69 ±.175	0.10	+0.59 ±.175	80	95	90	80
Edna	Wadge	1-3	23	100	0.61 ±.038	0.59 ±.043	-0.02 ±.057	0.02	-0.04 ±.057	None	--	--	--
Navajo	No. 6,7,8	1-3	23	100	0.50 ±.044	0.57 ±.077	+0.07 ±.089	0.03	+0.04 ±.089	None	--	--	--
Belle Ayr	Roland-Smith	1-3	6-10	100	0.54 ±.035	0.65 ±.030	+0.11 ±.046	0.02	+0.09 ±.046	None	--	--	--
Colstrip	Rosebud	1-3	12-13	100	0.67 ±.019	0.57 ±.056	-0.10 ±.059	0.04	-0.14 ±.059	None	--	--	--

[a] 100 mesh x 0 and 200 mesh x 0 is symbolized as 100 and 200, respectively.

[b] Increase due to ash removal; see Tables 18 and 19.

[c] Corrected to reduction in ash.

[d] Tested by using t test results with a significance of less than 70% (where σ = Δ organic sulfur) were not considered statistically important.

Table 21

SUMMARY OF ORGANIC SULFUR INCREMENTS[a]

Coal Basin	Median	Average	Low	High
All Samples (34)[b]	0.16	0.22 ± .124[c]	-0.23	+0.73
Appalachian (23)	0.22	0.23 ± .127	-0.23	+0.73
Interior (7)	0.45	0.31 ± .286	-0.05	+0.60
Western (4)	0.04	0.01 ± .100	-0.14	+0.09

[a] Increase in organic sulfur after leaching and after correction for reduction in ash content.

[b] Number of mine samples

[c] Pooled standard deviations

From an analytical point of view, a systematic error of 0.1% is easily possible and from a practical perspective, differences less than 0.1% are not important; therefore, the data were tested for statistical significance for differences of >0.1% w/w. Using this criterion, six coals had a >0.1% w/w organic sulfur increase with a significance of 90 or more percent, six were significant at the 80% level, and three at the 70% level. For a difference of >0.2% w/w, two were significant at the 90% level, five at the 80% level, and three at the 70% level. When tests were made for significance for differences >0.4% w/w, only the Weldon and Egypt Valley No. 21 coals had 80% or more significance.

These organic sulfur increases could result from three possible sources: (a) actual organic sulfur increases caused by either sulfonation or sulfation reactions, (b) apparent organic sulfur increases caused by formation of unextractable inorganic sulfur species during coal leaching, and (c) incomplete removal of elemental sulfur in the toluene extraction step. Partially oxidized coals, coals with many phenolic groups or other active sites, or highly porous coals with a large internal surface area should be prime candidates for sulfonation or sulfation. Coals of this type included in the survey are the Western and the Interior Basin coals.

In fact, these two groups of coals in general had a higher ferric ion consumption (see Table 12) than the Appalachian coals. Ferric ion oxidation of coal should typically produce phenols, alcohols and other reactive sites which could easily react with the sulfuric acid present in any extraction. Since both of these groups of coals did not show organic sulfur increases significantly different from Appalachian coals, the possibility of sulfonation or sulfation reactions does not seem likely.

Apparent organic sulfur increases could result from insoluble inorganic compounds, such as $CaSO_4$ or $Fe(OH)SO_4$, precipitating in the pores of tightly structured coal, as is the case for most Appalachian coals. Coals with high pyritic sulfur contents, such as Egypt Valley No. 21, Weldon, and Fox coals, could produce significant amounts of sulfate internally which could precipitate as $CaSO_4$ in the coal pores by reacting with CaO or $CaCO_3$ present in all coal ash, or could form insoluble $Fe(OH)SO_4$ under appropriate conditions. Even though the analytical procedure for hydrochloric acid extraction of sulfate sulfur was designed specifically to remove sulfate formed by oxidation or weathering and thus could easily miss deeply imbedded inorganic material, it seems unlikely that more than 0.1% sulfate sulfur could be missed in the analysis, even in the Appalachian coals.

The third possibility is the incomplete removal of the elemental sulfur in the toluene extraction step. Elemental sulfur would raise the total sulfur value but would not result in erroneously high pyritic or sulfate sulfur values. Because organic sulfur is calculated by difference, this additional sulfur would then result in a higher organic sulfur value. Since the extraction step has not been optimized and is presently performed only once, this source of error should be considered an excellent possibility. In addition, this residual elemental sulfur would be expected to be the greatest in the highly structured and small-pored Appalachian coals, and less in the more porous Internal Basin and Western coals. Because actual results follow these trends, this is considered the probable source of the organic sulfur increase. Additional experimentation is required to confirm this possibility and to establish tentative solutions.

In order to distinguish between these three possibilities, a series of experiments was run using the Warwick, Fox, Weldon, Egypt Valley No. 21, Delmont, and Homestead coals, which showed organic sulfur increases of 0.32, 0.49, 0.69, 0.82, 0.44, and 0.61% w/w, respectively, and representing both Appalachian and Interior Basin coals.

The first group of experiments was designed to determine whether or not unextractable inorganic species were being formed in the pores of these coals. Sulfate was first determined by the usual 5N HCl extraction on the whole coal in order to establish the amount of extractable sulfur. In a separate set of experiments, the organic matter was removed by a low temperature oxygen plasma technique at 150°C, which oxidizes the coal matrix without significant oxidation of pyrite to sulfate. A sulfate determination was then performed on the ash using standard procedures. The results summarized in Table 22 show that there is no significant difference between the sulfate found by either procedure. Thus, it can be concluded that the organic sulfur increases are not due to the formation of the unextractable inorganic species in the coal pores.

If the increases were due to sulfonation or sulfation reactions of the ferric sulfate leach solution, the use of ferric chloride to remove pyrite should result in no organic sulfur increase. Since this difference would be most striking for the Egypt Valley and Weldon coals which had organic sulfur increases of 0.82 and 0.69% w/w, these coals were extracted in duplicate with ferric chloride, and the organic sulfur content was followed as a function of time. The results of these experiments, listed in Table 23, show a steady increase in organic sulfur content in both cases as the pyrite was extracted. In addition, samples taken at intermediate times which were not extracted with toluene had much higher organic sulfur increases than those that were extracted once with toluene.

When compared to ferric sulfate leaching, both coals had slightly smaller organic sulfur increases (Table 23). These differences, which were 0.16% w/w for the Weldon coal and 0.30% w/w for the Egypt Valley coal, could be an indication of a small amount of reaction of the ferric sulfate leaching reagent with the coal; but given both experimental and analysis variables, this cannot be established using the present data.

Table 22

SULFATE DETERMINATION ON WHOLE COAL AND PLASMA ASH[a]

Coal Mine	% W/W SULFATE	
	Whole Coal	Plasma Ashed
Warwick	0.14	0.12
Egypt Valley	0.12	0.22
Fox	0.09	0.07
Weldon	0.18	0.11

[a] Determination in both cases by the standard ASTM method and based on whole coal weight.

Table 23

ORGANIC SULFUR CHANGES WITH FERRIC CHLORIDE[a]

Coal	Time (hr)	Sulfur Content, % w/w	
		Pyritic	Organic
Egypt Valley	0.0	5.07[b]	1.34[b]
	2.0	1.01	2.48
	5.5	0.34	1.70[c]
	23.0	0.00	1.86[c]
Ferric Sulfate	23.0	0.38	2.16[c]
Weldon	0.0	5.24[b]	1.00[b]
	1.5	1.73	1.89
	4.0	0.66	2.23
	10.0	0.20	2.26
	23.0	0.00	1.53[c]
Ferric Sulfate	23.0	0.47	1.69[c]

[a] All extractions used the same procedure as the ferric sulfate runs; each coal was extracted in duplicate and the results averaged.

[b] Initial value for ROM coal.

[c] Extracted with toluene before analysis.

Thus, it is felt that the observed increases are not due to reaction of the leaching reagent with the coal, but rather are due to incomplete removal of elemental sulfur from coal in the toluene extraction step.

Incomplete removal of elemental sulfur is a logical result of the experimental method also because no attempt was made to optimize sulfur removal and only a single toluene extraction was made. A check for sulfur recovery on all 34 toluene extracts showed that sulfur recovery averaged 55 ± 15%, compared to 85-97% that is routinely obtained in our bench scale work(1,3) where a double toluene extraction and careful sulfur mass balance is made. Since a single toluene extraction is sufficient to remove elemental sulfur from some coals and is obviously inadequate in other cases, it is important that experimentation be conducted in order to determine the degree and severity of extraction that are necessary to remove the elemental sulfur from a wide range of coals.

Favorable results obtained in vaporization of residual elemental sulfur and sulfate in earlier work on the Meyers Process indicated that similar treatment of coals which had apparent incomplete elemental sulfur and/or sulfate removal could lead to significant additional sulfur reductions and could further verify the source of the organic sulfur increases. Thus, two examples — the Delmont and Warwick coals — were chosen in which reduction of the organic sulfur (i.e., removal of remaining elemental sulfur) would allow the treated coal to meet EPA's most stringent new source standards. An additional coal from the Homestead Mine representative of the Interior Basin, which could be reduced below most Priority 2 and 3 state standards, was chosen as the third example. Analyses of these coals before vaporization treatment are shown in Table 24.

Each of the coals was treated in duplicate in ceramic boats for 3 hrs at 370°C in a tube furnace under a 1-liter/minute flow of argon or argon/hydrogen. The results based on total sulfur analysis listed in Table 25 show that substantial amounts of additional sulfur were removed in all three cases. The Delmont and Warwick coals were reduced enough to meet EPA's new source standards. The Homestead coal was reduced by a substantial 0.83% indicating that not only all the residual sulfur was removed, but also most of the residual sulfate. Note also that the presence of

Table 24

ANALYSIS OF LEACHED AND TOLUENE EXTRACTED COALS BEFORE VAPORIZATION TREATMENT

Mine	% W/W Sulfur				
	Total	Pyritic	Sulfate	Organic	Initial Organic[a]
Delmont Mine, Upper Freeport Seam	0.96	0.21	0.06	0.69	(0.25)
Warwick Mine, Sewickley Seam	0.82	0.09	0.14	0.59	(0.27)
Homestead Mine, No. 11 Seam	2.38	0.22	0.30	1.86	(1.25)

[a] Organic sulfur content of run-of-mine coal before ferric sulfate leaching.

Table 25

ANALYSIS OF EXTRACTED COALS FROM SURVEY PROGRAM AFTER VAPORIZATION TREATMENT[a]

Mine	% W/W Total Sulfur		
	Starting[b]	Ar(370°C)	Ar/H_2(370°C)
Delmont Mine,	0.96	0.80	0.64
Upper Freeport Seam	ΔS (loss)	0.16	0.32
Warwick Mine,	0.82	0.61	0.56
Sewickley Seam	ΔS (loss)	0.21	0.26
Homestead Mine,	2.38	1.71	1.55
No. 11 Seam	ΔS (loss)	0.68	0.83

[a] Average of duplicate runs.

[b] From Table 24

hydrogen in the vaporization gas increased sulfur removal significantly in all cases. These results essentially prove the hypothesis that organic sulfur increases in treated coals are the result of incomplete toluene extraction.

These very promising results indicate that treatment of additional survey coals by this technique could result in significantly lower sulfur values of treated coals by removing sulfate in those cases where it was high and elemental sulfur in those cases where its removal was incomplete. An examination of the data indicates that approximately 20 out of a total of 35 coals could benefit from this treatment. In addition, it is possible that vaporization could be developed into a viable alternative to toluene extraction in the overall process. This alternative must be explored in any future research.

4.3.9 Miscellaneous Data

Table 26 contains miscellaneous data which were accumulated during this survey and which are treated briefly in the paragraphs below:

> The Filtration Rates of the various coals are qualitatively shown in Table 26. These observations are based on the amount of time required to obtain a dewatered filter cake. A label of fast (F) indicates no problem in filtration, with the rate proceeding near the maximum rate of the funnel; medium (M) indicates a slower, but still acceptable rate; and slow (S) indicates that unacceptably long times were required for filtration. It was found that the rate of filtration closely follows the ash content of the treated coals, with high ash coals filtering much slower than low ash coals. In the case of 200 mesh x 0 coal from the Camp Nos. 1 & 2 mine (No. 11 seam) which filters very slowly, the removal of excess ash by density fractionation at 1.90 specific gravity changes its filtration rate from slow to very fast. Thus, the use of cleaned coal could substantially reduce filtration requirements in any commercial plant.
>
> Liquid Retention in the form of leach solution and toluene was also determined under a set of standard, but not optimum, conditions and is expressed as g liquid retained per 100 g coal. In both cases, the vacuum filtration was continued 3 minutes after no more liquid was visible on top of the filter cake. Table 26 indicates that in both cases coal to coal variations were within experimental error and toluene is retained to a lesser extent than the leach solution. These results are consistent with the postulate that the liquid is being held

Table 26

MISCELLANEOUS DATA

Mine	Seam	Mesh	Free Swelling Index		Rank		Liquid Retention in g/100g Coal		Filtration Rate	Ash Content[a]
			Initial	Extracted	Initial	Extracted	Leach Soln.	Toluene		
Warwick	Sewickley	100	4-1/2		hvAb	hvAb			M	H
Muskingum	Meigs Creek No. 9	150			hvAb	hvAb	25	39	F	L
Egypt Valley No. 21	Pittsburgh No.8	100	4	4	hvAb	hvAb			F	M
Powhattan No. 4	Pittsburgh No. 8	100			hvAb	hvAb	38	30	S	H
Isabella	Pittsburgh	100			hvAb	hvAb	41	33	S	H
Mathies	Pittsburgh	150			hvAb	hvAb	43	32	S	H
Williams	Pittsburgh	100			hvAb	hvAb	[illegible]	33	F	L
Humphrey No. 7	Pittsburgh	100	8	8-1/2	hvAb	hvAb			M	L
Robinson Run	Pittsburgh	150			hvAb	hvAb	41	40	F	L
Shoemaker	Pittsburgh	100			hvAb	hvA	40	30	S	H
Delmont	Upper Freeport	200			hvAb	hvAb	45	30	M	M
Marion	Upper Freeport	100			mvb	mvb	37	24	M	M
Jane	Lower Freeport	100	6-1/2	5	hvAb	hvAb			F	M
Lucas	Middle Kittanning	100			hvAb	hvAb	43	30	F	L
Bird No. 3	Lower Kittanning	150			lvb	lvb	39	27	F	M
Fox	Lower Kittanning	100	6	7	hvAb	hvAb			F	L
Martinka	Lower Kittanning	100	1-1/2	0	hvAb	hvAb	46	36	S	H
Meigs	Clarion 4A	100			hvBb	hvBb	38	32	S	M
Dean	Dean	150	5-1/2	3-1/2	hvAb	hvAb	35	33	F	L
No. 1	Mason	100			hvAb	hvAb			M	L
Kopperston No. 2	Campbell Creek	100	7	5-1/2	hvAb	hvAb	37	27	F	M
Harris Nos. 1&2	Eagle & No.2 Gas	100	7	7	hvAb	hvAb	29	31	F	L
North River	Corona	100			hvAb	hvAb	39	27	F	H
Orient No. 6	Herrin No. 6	100	4-1/2		hvAb	hvCb			S	M
Homestead	No. 11	100		0	hvBb	hvBb	53	43	M	H
Eagle No. 2	Illinois No. 5	100	6	2-1/2	hvAb	hvAb			M	M
Camp Nos. 1&2	No. 9 (W. Ky.)	100	5	0	hvBb	hvBb			S	M
Ken	No. 9	100			hvBb	hvBb	30	31	M	L
Star	No. 9	150		0	hvBb	hvBb	35	27	M	L
Weldon	Des Moines No. 1	100	1	0	hvCb	hvCb			M	L
Edna	Wadge	100	0.5	0	hvCb	hvCb			M	L
Navajo	Nos. 6,7,8	100	0	0	hvCb	subA			F	M
Belle Ayr	Roland-Smith	100	0	0	subA	subB			F	L
Colstrip	Rosebud	100	0	0	subB	subB			F	L

[a] Low, 0-17%, Medium, 17-27%, High >27%, see text for details.

in the spaces between the coal particles, and that the differences between the leach solution and toluene merely reflect the fact that toluene is less dense than the leach solution.

The Free-Swelling Index (FSI) is an indication of the caking qualities of a coal and therefore has some importance in evaluation of a coal for coking and for use in certain types of steam boilers. The data show that, for coals that have high excess reactivity with ferric ion (such as the Eastern Interior Basin coals), the FSI is substantially reduced. Coals having little excess reactivity with ferric sulfate (such as the Appalachian Basin coals) have little or no change upon treatment. This is consistent with the generally accepted idea that slight oxidation of a coal reduces its FSI.

The Rank of the treated and untreated coals is the same in all instances except for the Orient No. 6, Belle Ayr and Navajo coals. Because rank is determined only by heat content for hvAb and lower ranked coals, and because rank is quite insensitive to small btu changes, only minor differences in rank should be expected.

4.4 FLOAT-SINK TESTING

Float-sink testing (washability studies) were run on thirty-one of the thirty-five coals by the Commercial Testing and Engineering Company in order to determine how conventional float-sink procedures compare to the Meyers Process in efficiency of pyrite removal, heat content change, and ash loss. In addition, information was obtained that can be used to evaluate a combined two-step process, involving coal washing followed by the Meyers Process, that would produce coal containing minimum amounts of pyrite and ash and a maximum heating value.

4.4.1 Procedures

The mine samples, representing 20 mines and coal seams, were selected, sampled and prepared according to the procedures described in Section 4.2 and Appendix A of this report. No tests were run on the four samples from the Edna, Navajo, Belle Ayr and Colstrip mines, since they contained less than 0.3% w/w pyritic sulfur and 1.0% total sulfur and were judged economically unfeasible for removal of pyritic sulfur by washing.

Five hundred pounds each of the 1-1/2" x 100 mesh, 3/8" x 100 mesh and 14 mesh x 0 portions prepared from the initial samples of the coals were fractionated according to standard float-sink procedures using organic liquids of 1.30, 1.40, 1.60 and 1.90 specific gravities. Samples of each size (head sample), of each gravity portion, and of the two 100 mesh x 0 samples, were analyzed on a dry basis for % w/w ash, total sulfur and pyritic sulfur.

The raw data were then used to calculate washability data showing cumulative recovery and cumulative reject at the various specific gravities for each of the size portions. A complete set of tables showing all new data is included in Appendix E. The remaining data have been reported previously(2).

4.4.2 Results and Discussion

Table 27 shows the summary of the results for the 14 mesh x 0 portions of 1.90 and 1.60 specific gravities and how they compare to the Meyers Process (100 mesh x 0 coal) for the total sulfur and pyritic sulfur reductions and ash removal. The 14 mesh x 0 float-sink material was

Table 27

SUMMARY OF FLOAT-SINK TESTS
14 MESH x 0 COAL
COMPARISON TO MEYERS PROCESS
100 MESH x 0 COAL

		Initial Analysis % w/w			Washed Coal Analysis, % w/w								Meyers Process[b] Final Analysis, % w/w			
					1.90 Float Material				1.60 Float Material							
Mine	Seam	% Total Sulfur	% Pyritic Sulfur	% Ash	% BTU Recy[a]	% Total Sulfur	% Pyritic Sulfur	% Ash	% BTU Recy[a]	% Total Sulfur	% Pyritic Sulfur	% Ash	% BTU Recy[a]	% Total Sulfur	% Pyritic Sulfur	% Ash
Warwick	Sewickley	1.37	1.03	40.47	93	1.02	0.54	17.02	89	0.92	0.41	12.96	99	0.66	0.06	35.32
Muskingum	Meigs Creek No. 9	6.08	3.65	21.68	96	4.36	1.99	19.18	89	4.17	1.69	16.82	97	3.22	0.24	16.05
Egypt Valley No. 21	Pittsburgh No. 8	6.55	5.07	25.29	96	4.63	3.42	11.86	92	4.27	3.03	10.25	98	[illegible]	[illegible]	18.69
Powhattan No. 4	Pittsburgh No. 8	4.12	2.57	37.17	93	3.27	1.89	17.40	88	3.04	1.51	12.37	100	1.94	0.04	32.13
Isabella	Pittsburgh	1.57	1.07	42.22	95	1.40	0.59	14.93	89	1.40	0.41	9.39	100	0.72	0.06	35.72
Mathies	Pittsburgh	1.46	1.05	41.01	95	1.67	1.02	14.89	90	1.62	0.93	11.94	100	0.94	0.05	36.43
Williams	Pittsburgh	3.48	2.23	13.16	98	2.32	0.88	7.62	97	2.15	0.69	7.09	99	1.74	0.29	9.16
Humphrey No. 7	Pittsburgh	2.53	1.59	9.88	99	1.91	0.90	6.97	97	1.82	0.81	6.45	99	1.49	0.14	66.97
Robinson Run	Pittsburgh	4.38	2.83	13.36	97	3.01	1.24	7.95	95	2.81	1.02	7.21	99	2.20	0.08	7.63
Shoemaker	Pittsburgh	3.51	2.19	33.48	96	3.62	2.07	12.23	92	3.22	1.67	8.62	99	1.73	0.08	28.87
Delmont	Upper Freeport	4.89	4.56	27.18	92	2.13	1.38	10.29	90	1.84	1.09	8.72	99	0.96	0.21	20.44
Marion	Upper Freeport	1.37	0.90	26.40	95	1.17	0.58	10.04	91	1.10	0.50	7.98	100	0.68	0.04	22.61
Jane	Lower Freeport	1.85	1.44	21.75	97	0.78	0.80	11.15	95	0.70	0.31	9.40	98	0.69	0.14	17.99
Walker	Upper Kittanning	0.71	0.07	16.67	98	0.66	0.07	12.17	93	0.66	0.07	9.59	c	c	c	c
Lucas	Middle Kittanning	1.79	1.42	9.68	98	0.67	0.32	5.80	97	0.62	0.27	5.04	100	0.63	0.07	6.32
Bird No. 3	Lower Kittanning	3.14	2.87	30.23	93	1.52	0.39	9.89	91	1.40	0.75	7.25	98	0.80	0.13	24.17
Fox	Lower Kittanning	3.83	3.00	13.55	96	2.00	1.32	8.73	95	1.99	1.21	7.44	96	1.64	0.26	9.72
Martinka	Lower Kittanning	1.96	1.61	49.64	91	0.84	0.46	21.53	85	0.75	0.30	14.69	(93)	0.58	0.12	43.46
Meigs	Clarion 4A	3.73	2.19	26.53	95	2.83	1.07	14.10	91	2.67	0.84	11.00	98	1.94	0.17	20.38
Dean	Dean	4.09	2.62	17.28	96	3.05	1.26	12.65	92	2.98	1.20	11.69	99	2.08	0.17	13.66
No. 1	Mason	3.12	1.98	11.39	97	2.29	1.03	6.77	96	2.15	1.88	6.11	[illegible]	1.72	0.21	3.50
Kopperston No. 2	Campbell Creek	0.91	0.47	30.15	[illegible]	[illegible]	0.34	11.31	92	0.79	0.28	[illegible]	[illegible]	[illegible]	0.04	25.53
Harris Nos. 1 & 2	Eagle No. 2 Gas	1.00	1.89	18.63	96	0.92	0.86	13.14	98	0.87	0.30	[illegible]	[illegible]	[illegible]	0.04	16.46
North River	Corona	2.06	1.42	49.25	95	[illegible]	1.03	19.57	91	2.07	0.93	[illegible]	(94)	0.93	0.14	42.84
Orient No. 6	Herrin No. 6	1.66	1.30	22.51	99	1.39	0.97	10.35	96	1.34	0.75	8.96	94	0.93	0.06	13.95
Homestead	No. 11	4.46	3.11	16.56	97	3.25	1.71	10.61	95	3.07	1.59	[illegible]	96	[illegible]	0.22	11.50
Eagle No. 2	Illinois No. 5	4.29	2.64	26.53	97	2.92	1.53	12.52	94	2.77	1.35	[illegible]	97	1.97	0.11	19.49
Camo Nos. 1 & 2	No. 9 (W. Ky)	4.51	2.31	21.13	96	2.90	1.22	10.21	91	2.75	1.01	8.49	98	2.02	0.14	15.77
Ken	No. 9	4.83	2.85	15.08	97	3.47	1.55	10.92	96	3.37	1.44	9.46	97	2.78	0.28	9.44
Star	No. 9	4.32	2.60	13.90	95	3.01	1.67	10.47	97	2.92	1.57	10.02	96	2.46	0.06	8.58
Weldon	Des Moines No. 1	6.39	5.24	15.74	97	3.91	2.72	3.81	95	3.81	2.60	8.20	98	2.25	0.15	5.94

[a] See text for method of calculation of recovery (Recy)

[b] Best run

[c] Not run due to low pyritic sulfur

chosen even though it may be too fine to be used in a commercial installation, because in most instances the best results were obtained with this top size. A series of telephone contacts was made with all the mine operators in this study in order to verify this assumption. These contacts indicated that, of those mines which also clean coal before shipment, that the resulting sulfur and ash contents obtained from the 1.90 float 14 mesh x 0 material are roughly equal to the sulfur and ash contents of the coal presently being shipped from the corresponding preparation plants. The 1.60 float data are included to illustrate what can be produced from a coal preparation plant with a sharply increased reject fraction. In addition, the current trend as the result of the current coal (and energy) shortage has been to decrease rejects, with concomitant increasing of the sulfur and ash content, in order to increase production. For these reasons, it is felt that the 1.90 float 14 mesh x 0 fraction represents a conservative basis for comparing the efficiency of coal cleaning to the Meyers Process.

In several cases, including the Humphrey No. 7, Marion, Dean, Eagle No. 2, Ken and Star mines, the 38.1 mM x 149μ (1-1/2" x 100 mesh) portions gave similar or slightly better results than the 1.41 mm x 0 (14 mesh x 0) portions, while better results were observed with the coarse fraction for the Shoemaker, Meigs, Homestead and Weldon coals. With all other coals, coal cleaning potential decreased when coarser material was washed.

The percent float-sink btu/lb loss (see Table 27 for tabulation of results) was calculated from the percent w/w and ash content of the cumulative material which was rejected at the specific gravity of interest. This value was assumed to represent the total heat content loss and was subtracted from 100% to give the btu recovery. Complete organic material recovery was assumed for the Meyers Process because no evidence has been found to date that indicates material other than ash is dissolved in the leaching process. The percent recovery was then calculated using the before and after dry-mineral-matter-free heat content of the coal.

The analysis of the 1.90 float material shows that 0.0-1.9% w/w more total sulfur is removed from the coal by the Meyers Process than by the float-sink method, with a median value of 0.7% w/w. For the 1.60 float material, the corresponding figures are 0.0-1.6% w/w with a median value of 0.6% w/w. The majority of the remaining total sulfur values obtained for both specific gravities were between 0.4 and 1.0% higher by the float-sink method than by the Meyers Process.

The advantages of chemical leaching are even more apparent in the final pyritic sulfur values where, for all but one coal, the final values are between 0.0 and 0.3% w/w. Float-sink separation at a specific gravity of 1.90 resulted in final pyritic sulfur values of 0.3 to 3.4%, which drop to 0.3 to 3.0% at a specific gravity of 1.60. The corresponding median values are 1.1 and 1.0% w/w, respectively. The 1.90 float material of the low sulfur Harris Nos. 1 and 2 and Kopperston No. 2 mines as well as the Warwick, Jane, Lucas and Martinka mines had final pyritic sulfur values of 0.3-0.5%, making them possibly competitive with the Meyers Process. Note, however, that 90% pyrite removal is not always reflected in the total sulfur values due to slight increases in other sulfur forms. Although for approximately one-half of the coals the Meyers processing results are already near optimum (see Table 1), additional processing improvements will be necessary to reach near optimum values for the others. However, in all cases the Meyers Process reduced the total sulfur content of the coals lower than that obtainable by conventional coal cleaning. In most cases, the differences were substantial.

The heat content recovery for the 1.90 float material is 96 ±2% and for the 1.60 float material, it is 93 ±3%. In contrast, chemical leaching results in 99 ±1% recovery for the Appalachian coals and 96 ±3% for the Eastern and Western Interior basin coals. Thus, chemical leaching and washing the Interior Basin coals at a specific gravity of 1.90 result in comparable heat losses, while in all other categories the Meyers Process is superior with respect to heat content recovery. In addition, oxidation of the coal during the leaching process results in an in situ generation of heat which can be used to supply process heat requirements for the Meyers Process, while losses due to washing are discarded with the refuse and in some cases may even present a fire hazard. Thus, for almost every coal, the Meyers Process is more efficient than physical separations with respect to energy recovery.

Table 27 also summarizes ash changes as the result of both processes. Note that in most cases, especially the Warwick, Isabella, Mathies, Shoemaker, Bird No. 3, Martinka, Kopperston No. 2 and North River mines, substantially more ash is removed by physical cleaning compared to the Meyers Process (in which only ash corresponding to pyrite is removed). Only in low ash cases, such as the Fox, Williams, Humphrey No. 7, Robinson Run, Lucas, Fox, Dean, No. 1, Homestead, Ken, Star, and Weldon coals, are both processes comparable. With the Walker coal, which has essentially zero pyritic sulfur, only ash reduction was achieved. However, ash reduction in itself is valuable in that reduced shipping costs, reduced load on electrostatic precipitators and enhanced heating values are realized. In addition, a certain part of the ash is soluble in the leach solution of the Meyers Process and any initial ash reduction should reduce both purification requirements on this solution and, depending upon pyrite reduction, on operating costs of the Meyers Process. Thus, depending on the situation, a simple cleaning procedure on most coals, and especially those containing >15% w/w ash, would be advantageous prior to treatment with the Meyers Process.

4.5 REMOVAL OF TRACE ELEMENTS

In the last few years, the potential environmental hazards of trace elements emitted in the flue gas from coal combustion has become a matter of concern(9-14). In view of this interest, it seemed appropriate to perform a survey of trace element concentrations in the coals selected for this project, and to examine removal efficiencies by both the Meyers Process and physical cleaning. This has been accomplished for 20 coals representative of the Appalachian, Eastern Interior and Western coal basins for the elements Ag, As, B, Be, Cd, Cr, Cu, F, Hg, Li, Mn, Ni, Pb, Sb, Se, Sn, V, and Zn.

4.5.1 Analysis Procedures and Results

In selecting procedures for the elements of interest, three major factors were considered. First, a sensitivity of 1 ppm (dry weight of whole coal) was selected as the lowest possible level of interest with the exception of Hg, where 0.1 ppm was used. This value was selected on the basis that if 100% of the element were emitted from the stack, 1 ppm in the feed coal would result in an emission of only 45 g/hr (0.1 lb/hr) from a 100 MW utility which, by all available information, seemed to be a conservatively safe emission level. Secondly, the analytical method chosen should have an overall accuracy of ±10% so that removal efficiencies could be accurately determined. The third factor considered was cost. On the basis of the survey nature of this task and the uncertain environmental hazards associated with the selected trace elements, it was decided that extensive methods development studies were not warranted and that relatively inexpensive procedures should be used. In several cases, the first two requirements were relaxed where added costs of meeting the requirements seemed excessive for the added value. Based on these criteria, all the trace analyses except those for As, B and F were performed using atomic absorption spectroscopy. The elements As and B were determined spectrophotometrically, while F was determined using a specific ion electrode technique. Details of the procedures and all of the raw data from the analyses are presented in Appendix F. In the case of Se, the method chosen appeared to perform well only on occasion and the results are so mixed that all of the data presented is highly suspect. Several studies are currently being conducted on a reliable Se method for coal.

The aforementioned procedures have been checked by comparing TRW analysis results of NBS Sample 1632 with NBS reported values and are summarized in Table 28. Recently, a large scale interlaboratory comparison of trace element results for coal using SRM 1632 was completed by the U.S. Environmental Protection Agency and the National Bureau of Standards(14). The mean values obtained from all other participating laboratories for the trace element concentrations are also included in Table 28.

Referring to Table 28, it can be seen that analyses for elements As, Be, Cu, Hg, Mn, Ni, Pb and Zn all show fair to excellent agreement with the certified NBS values both in accuracy and precision. The value obtained for vanadium is in good agreement with the reported NBS value; however, the precision between replicate samples is poor. This poor precision is not indicative of the precision normally obtained with coal samples, which is typically ±24% relative deviation. The value obtained for Cr is approximately 18 ppm higher than the NBS reported value, which might be attributed to contamination or incorrect background correction. The cadmium value reported by TRW is 2 ppm higher than the NBS reported value. However, the range of values reported is approaching the lower limit of detectability for this element by AAS and for this reason will show a large degree of scatter and inaccuracy. The difficulty with the Cd analysis is not limited to the TRW results, since all laboratories had difficulty with this analysis; this is apparent when the mean value of 0.9 is compared with the NBS certified value of 0.19. No fluoride values

Table 28

COMPARATIVE TRACE ELEMENT ANALYSIS RESULTS[a] (PPM IN MOISTURE-FREE COAL)

Element	NBS 1632 Certified Values	EPA-All Labs Grand Mean	TRW	Illinois State Geological Survey[b]					
				Neutron Activation	Atomic Absorption		Optical Emission	X-Ray Fluor.	Ion Elec.
					LTA	HTA			
As	5.9 ± 0.6	6.24	5.0 ± 0.64	5.7					
Ag			1 ± 0.7						
Cd	0.19 ± 0.03	0.9[d]	2.4 ± 0.14		<0.4	<0.4			
Cr	20.2 ± 0.5	22.7	38 ± 2.8		24	22	22		
Cu	18 ± 2		15 ± 1.4		18	23	28	22	
Hg	0.12 ± 0.02	0.22	0.10 ± 0.0	0.18					
Li			28 ± 0.0						
Mn	40 ± 3	41.3	39 ± 1.4	39					
Ni	15 ± 1	19.0	18 ± 0.7		16	16	26	22	
Pb	30 ± 9	30.4	30 ± 1.4		22	32	24	26	
Se	2.9 ± 0.3	4.6		2.8					
Sb			4.8 ± 3.2				0.2[c]		
Sn			4 ± 5.2				2[c]		
Tl	0.59 ± 0.3								
Th	(3)[e]								
U	1.4 ± 0.1	1.7							
V	35 ± 3	34.9	32 ± 20				54		
Zn	37 ± 4	29.5[d]	33 ± 1.4		40	38		49	
Fe	8700 ± 300							1.12	
Be	(1.5)[e]	1.75	2.0 ± 0.1				1.72		
F		83.5[d]	73 ± 7						80.4
B			32 ± 11				43[c]		

[a] Table taken from Reference 8; TRW values added.

[b] Average of at least four or more determinations.

[c] Values reported separately in Reference 8.

[d] Questionable mean; wide scatter or limited data.

[e] Information value only. Not certified by NBS.

are reported by NBS; however, several spiked samples were analyzed to check the procedure employed for recovery of added fluoride. The percent recovery obtained was 85%, suggesting that TRW reported values might be slightly lower than the true value. Analysis results which have recently been reported by the Illinois Geological Survey (IGS) for SRM 1632 have included additional results for F, B, Sn, and Sb. TRW results are in good agreement for F, B, and Sn but are in poor agreement for Sb. There are no comparative analyses available for the elements Ag and Li, so no comment can be made as to the relative accuracy of the procedures employed.

The results of trace element analyses for 18 elements in 10 coals before and after treatment by the Meyers Process and by deep cleaning are presented in Appendix F, Tables F-2 through F-11. The first group of 10 coals was reported in the final report(2) of the preceding coal survey program and are included only in summary here. A summary of the trace element levels in the untreated coals appears in Table 29. The analyses were run in triplicate for the first survey program and in duplicate on both untreated and treated coals for the present survey program. The change from triplicate to duplicate analyses was a cost saving step but resulted in slightly less precision for the second phase of the program.

Up to 22 sets of calculated standard deviations (σ) for each element in the untreated coal were used to calculate a pooled standard deviation (S) for each element. The same was done for coal extracted by the Meyers Process and for the washed coal. The pooled standard deviation is calculated as follows:

$$S = \sqrt{\frac{\phi_1\sigma_1^2 + \phi_2\sigma_2^2 + \ldots\ldots\phi_n\sigma_n^2}{\phi_1 + \phi_2 + \ldots\ldots\ldots\ldots\phi_n}}$$

where

σ = standard deviation for a given set of analyses

ϕ = number of analyses in a given set

The results of these calculations are given in Table 30 and show that on both an individual and an average basis, the analysis results for the treated coal are generally as precise as the untreated coal. Thus, the manipulation required in coal leaching apparently either did not introduce significant contamination or was introducing contamination in a fairly uniform way.

Further examination of the data in Table 30 shows that 4 of the 18 elements studied occurred in the coals at levels which may be of minimal environmental significance from coal combustion facilities in terms of the limit of 5 ppm, which was set for the purpose of this study. The elements which normally occurred below this level are Ag, Be, Cd, and Hg.

Table 29

TRACE ELEMENT COMPOSITION OF UNTREATED COALS (PPM)

Element	Appalachian Coal Basin														Eastern Interior Basin				Western Coals	
	Muskingum	Mathies	Robinson	Powhattan	Delmont	Marion	Lucas	Bird #3	Meigs	Egypt Valley #21	Jane	Fox	Warwick	Humphrey #7	Ken	Eagle #2	Orient #6	Camp Nos. 1 & 2	Belle Ayr	Colstrip
Ag	2.3	1.8	1.6	0.8	2.6	1.5	2.0	2.9	0.8	4	2	<0.1	4	0.5	1.4	<0.1	<0.1	8	<0.1	<0.1
As	2.0	6.1	5.9	4.3	40	98	74	16	2.6	22	29	24	13	9	6.5	6.6	15.2	5.7	0.4	<0.01
B	54	54	60	62	18	10	20	30	115	34	27	16	20	26	6.0	30	43	272	11	35
Be	2.0	2.7	0.6	3.3	4.2	2.2	3.8	3.6	1.4	0.7	0.8	2.0	1.0	0.4	2.0	0.5	6	1.5	<0.5	0.5
Cd	1.6	0.9	1.8	1.2	1.8	1.5	1.4	1.4	0.8	<0.5	<0.5	<0.5	<0.5	<0.5	1.7	0.5	0.7	0.8	0.6	<0.5
Cr	110	110	100	141	144	76	52	149	100	55	55	94	81	26	76	126	74	122	<0.5	<0.5
Cu	15	29	10	25	20	38	13	26	23	26	35	25	24	16	16	18	36	17	27	8
F	117	210	100	222	131	155	65	105	222	168	122	94	251	78	124	151	105	215	48	29
Hg	0.09	0.09	0.14	0.07	<.02	0.06	<0.2	0.10	0.05	0.31	0.11	0.07	0.14	0.06	<0.2	0.16	0.12	0.16	0.22	0.20
Li	55	64	12	52	24	76	8	54	22	26	38	4	76	13	9	4	23	10	<0.3	4
Mn	25	66	42	57	94	25	15	45	44	41	46	24	31	31	60	86	57	38	48	87
Ni	29	34	26	37	68	23	35	36	22	41	33	147	44	17	30	136	53	27	61	31
Pb	12	19	12	20	31	15	18	23	12	15	25	5	16	7	16	29	0.5	25	3	3
Sb	<5	<5	19	<5	16	<5	<5	<5	9	<5	<5	<5	<5	<5	24	<5	<5	<5	<5	<5
Se	59	74	49	54	25		8		63	<5	<5	17	<5	<5	15	<5	<5	<5	5	<5
Sn	15	12	8	<5	20	<5	10	15	15	<5	<5	<5	<5	<5	12	<5	<5	<5	<5	<5
V	33	60	28	60	40	54	12	60	50	102	147	94	78	77	35	64	69	105	1	103
Zn	30	41	30	40	76	34	50	60	38	31	34	105	55	18	40	215	25	97	49	9

Table 30

TRACE ELEMENT ANALYTICAL PRECISION

Element	Average Concentration (ppm)	Pooled Standard Deviation (ppm)				% Relative Standard Deviation for All Samples
		Untreated Coal	Meyers Process	Float Sink	All Samples	
Ag	2.5	1.32(15)*	1.91(12)	0.16(5)	1.48	59
As	11.4	1.78(21)	1.22(12)	1.80(8)	1.64	14
B	48.1	3.85(22)	5.49(19)	1.96(10)	4.59	10
Be	2.0	0.39(19)	0.20(19)	0.52(9)	0.36	18
Cd	1.3	0.26(21)	0.42(9)	0.63(10)	0.42	32
Cr	71.3	4.26(20)	4.10(20)	1.83(10)	3.83	5
Cu	20.4	2.18(22)	3.08(19)	1.76(10)	2.49	12
F	125.2	11.18(21)	18.50(19)	8.57(9)	14.13	11
Hg	0.13	0.03(18)	0.054(9)		0.04	31
Li	25.1	3.77(21)	3.65(20)	1.11(10)	3.36	13
Mn	39.7	4.74(22)	2.44(20)	1.74(10)	3.52	9
Ni	43.5	6.16(22)	6.15(19)	7.94(10)	6.54	15
Pb	23.0	3.51(21)	7.19(19)	4.38(10)	5.35	23
Sb	12.0	5.77(8)	3.96(4)	7.17(10)	6.19	52
Se	18.3	5.91(5)	1.15(2)		5.03	27
Sn	26.0	9.91(7)	9.14(8)	9.94(10)	9.68	37
V	58.0	15.81(22)	14.98(19)	4.98(10)	14.01	24
Zn	51.4	5.25(22)	4.73(20)	3.02(10)	4.69	9

*Values in parenthesis are numbers of sets of data used in the calculations.

In keeping with the low levels at which these elements were present, the percent relative deviations of these analyses were generally high: Ag, ±59%, Be, ±18%, Cd, ±32%, Hg, ±31%.

Seven of the remaining elements (As, Cu, Li, Pb, Sb, Se and Sn) were generally present in the range of 3-30 ppm, while the remaining seven (B, Cr, F, Mn, Ni, V and Zn) were generally above 30 ppm. The analytical precision of these fourteen elements, while not as good as had been hoped, was generally acceptable: As, ±14%, B, ±10%, Cr, ±5%, Cu, ±12%, F, ±11%, Li, ±13%, Mn, ±9%, Ni, ±15%, Pb, ±23%, Sb, ±48%, Se, ±32%, Sn, ±38%, V, ±24%, Zn, ±9%.

4.5.2 Removal Efficiencies

The removal efficiencies for trace elements from coal treated by the Meyers Process and by physical cleaning are summarized in Table 31. A discussion of the results on an element-by-element basis is presented in this section.

Ag - Due to the low values of Ag present in coal and the poor precision of the results, the data for Ag are somewhat inconclusive. However, in over half of the cases where there is a decided difference after treatment, 50% or more of the Ag has been removed.

As - Arsenic is easily and effectively removed by both treatments in almost every case. The Meyers Process is slightly more effective and removed at least 80% of the As in every case.

B - Boron is not appreciably removed from coal by either process except in isolated cases.

Be - Beryllium is not appreciably removed by either process except in isolated cases.

Cd - Due to the low values of Cd present in coal and the poor precision of the results, the data for Cd are somewhat inconclusive. The data suggest that Cd is removed by the Meyers Process, which is consistent with the reported(9) presence of Cd in the ZnS phase, since Zn is easily removed. The values for washed coals are inconclusive.

Cr - Chromium is removed by both treatments in almost every case by 50% or greater.

Cu - Copper is only moderately removed by either process.

F - There is only limited evidence of fluoride removal by the Meyers Process. Washing, however, shows 30-60% removal in nearly every case.

Hg - Due to the very low (0.1 ppm) levels of Hg in all coals examined, no data on removal are available.

Table 31

TRACE ELEMENT REMOVALS (% W/W)

Element	Condition	Appalachian Coal Basin														Eastern Interior Coal Basin				Western Coals	
		Muskingum	Mathies	Robinson Run	Powhattan #4	Delmont	Marion	Lucas	Bird #3	Meigs	Egypt Valley	[illegible]	Fox	Warwick	Humphrey #7	Ken	Eagle #2	Orient #6	Camp Nos. 1&2	Belle Ayr	Colstrip
Ag	M[a]	93±17	59±3	ND[c]	Gain[d]	ND	[illegible]	ND	ND	Ind[e]	50±15	ND	ND	ND	ND	ND	Gain	Ind	50±33	Ind	Ind
	Fs[b]	57±27	44±16	33±5	ND	62±8	[illegible]	[illegible]	88±24	Ind						28±17					
As	M		84±1	95±1		98±1	97±4	81±1	88±1		85±6	81±7	94±5	100	91±1	92±0	90±17	88±3	82±9	ND	Ind
	Fs		97±3	98±1		71±2	14±4	81±1	75±3							85±0					
B	M	ND	ND	ND	Gain	ND	ND	ND	53±1.3	13±1	ND	15±1	19±9	ND	38±9	13±6	ND	30±8	87±1	ND	86±2
	Fs	44±7	ND	ND	19±5	72±5	ND	ND	81±1	15±8						13±6					
Be	M	ND	33±8	ND	30±9	11±4	ND	ND	28±1	ND	43±16	38	32±14	ND	ND	Gain	Ind	92±48	67±27	Ind	Ind
	Fs	Gain	ND	ND	ND	52±7	54±3	11±4	Gain	19±10						50±0					
Cd	M	62±14	-38±24	ND	ND	37±11	67	ND	18±21	38	Ind	Ind	Ind	Ind	Ind	ND	Ind	71±45	ND	Ind	Ind
	Fs	Gain	Gain	Gain	Gain	Gain	ND	ND	ND	ND						ND					
Cr	M	53±8	49±4	63±1	40±2	33±8	50±5	40±1	59±3	57±1	ND	60±14	58±5	41±4	ND	53±2	71±5	23±6	45±30	Gain	Gain
	Fs	45±8	56±3	70±2	56±1	48±1	37±3	40±3	82±1	50±1						47±2					
Cu	M	ND	24±8	Gain	ND	ND	50±1	Gain	58±9	83±1	35±9	11±4	44±6	ND	ND	50±5	Gain	100±11	ND	19±7	Gain
	Fs	Gain	34±7	Gain	20±15	45±2	42±4	39±5	84±17	52±2						50±5					
F	M	Gain	ND	ND	21±1	ND	ND	11±1	ND	ND	21±8	ND	12±2	13±6	ND	56±6	ND	14±2	ND	44±9	ND
	Fs	28±7.2	58±5	ND	55±1	53±3	48±3	16±4	53±6	64±2						30±8					
Hg	M										ND	ND	Gain	[illegible]	Gain		ND	ND	ND	41±7	ND
	Fs																				
Li	M	ND	38±7	73±2	10±4	ND	19±1	15±9	ND	ND	ND	82±2	Gain	[illegible]	ND	ND	Gain	78±3	90±7	Gain	Gain
	Fs	72±16	19±4	58±1	67±3	51±3	64±1	33±9	70±7	51±2						33±8					
Mn	M	75±9	90±4	83±3	72±1	88±1	70±1	58±14	80±3	61±1	61±7	57±7	63±6	44±4	77±5	92±1	77±7	89±10	16±3	92±25	93±3
	Fs	ND	64±3	43±7	49±3	94±1	20±7	33±11	56±5	12±9						43±6					
Ni	M	41±21	53±3	31±1	27±19	41±1	Gain	ND	ND	ND	51±5	ND	93±1	51±5	41±9	47±12	65±10	Gain	Gain	89±6	58±5
	Fs	Gain	ND	ND	ND	68±2	Gain	-3±20	ND	ND						ND					
Pb	M	Gain	88±35	Gain	Gain	ND	ND	ND	Gain	ND	67±5	99±2	Gain	38±14	ND	75±7	[illegible]	Gain	ND	Gain	93±11
	Fs	Gain	Gain	Gain	ND	42±5	Gain	ND	ND	Gain						ND					
Sb	M	ND	Ind	84±7	Ind	75±17	Ind	Gain	Ind	99	Ind	Ind	Ind	Ind	Ind	ND	Gain	Ind	Ind	Ind	Ind
	Fs	Gain	Gain	Gain	Gain	91±4	Gain	Gain	Gain	Gain						58±22					
Se	M							75±30			Ind	Ind	85	Ind	Ind		ND	ND	Ind	ND	Ind
	Fs																				
Sn	M	ND	50±19	Ind	Gain	ND	Gain	ND	ND	ND	Ind	Ind	Ind	Ind	Ind	67±16	Ind	Ind	Ind	Ind	Ind
	Fs	Gain	Gain	Gain	Gain	Gain	Gain	ND	ND	ND						Gain					
V	M	ND	60±21	86±12	ND	Gain	Gain	ND	ND	16±10	36±1	ND	[illegible]	ND	[illegible]±21	4[illegible]	ND	ND	ND	Gain	98±11
	Fs	ND	63±19	82±11	32±9	Gain	ND	[illegible]	47±[illegible]	ND						20±13					
Zn	M	60±5	71±2	47±5	48±18	58±5	65±5	70±5	99±10	74±4	66±4	50±11	90±1	67±2	56±14	58±7	84±1	82±4	55±18	95±1	ND
	Fs	47±14	41±9	40±18	42±4	16±7	35±7	42±13	70±5	28±8						10±3					

[a] M=100 mesh x 0, a finer ROM coal treated by the Meyers Process.

[b] F_s=1.60 float fraction of 14 mesh x 0 coal treated by float-sink methods.

[c] ND=no statistically significant difference between initial and final values.

[d] Gain=treated coal showed increase in trace metal content.

[e] Ind=both initial and final values near or below level of detectability.

Li - Lithium is removed in only a few cases by the Meyers Process but shows 50-70% removal by washing in nearly every case.

Mn - Manganese is easily and effectively removed by the Meyers Process by 60-90% in most cases. Washing is nearly as effective but seems to remove slightly less than 40-70%.

Ni - Nickel is removed by the Meyers Process by 30-70% in most coals. Washing does not appear to be effective.

Pb - In several cases Pb shows excellent removal (70-90%) by the Meyers Process. For cases where both processes are analyzed, neither appears to be effective.

Sb - Due to the low values of Sb present in coal and the poor precision of the results, the data for Sb are inconclusive. However, in those cases where there is a high Sb concentration in the starting coal, Sb is effectively removed by the Meyers Process and to a lesser extent, by washing.

Se - No conclusion can be drawn due to the difficulties with the analyses.

Sn - Tin shows little signs of being removed by either process.

V - Vanadium shows moderate removal by either process, with slightly better results by washing.

Zn - Zinc is easily and effectively removed by either process in almost every case. The Meyers Process appears more effective (70-90%) than washing (30-40%).

4.5.3 Summary and Conclusions

Analyses of 50 coal samples, consisting of 20 as-received, 20 chemically extracted using the Meyers Process, and 10 undergoing float-sink separation have shown that both float-sink procedures and the Meyers Process are able to remove significant amounts of several trace elements. Although results vary from coal to coal as to elements extracted and the degree of extraction, some general conclusions can be reached.

- Elements commonly found in nature as sulfides are the calcophile elements, which include As, Co, Cu, Ni, Pb and Sb. The

Meyers Process appears to be more efficient than float-sink procedures in removing these elements. The Meyers Process has demonstrated removal of As, Cu, Ni, Pb, and Sb, whereas float-sink procedures removed only As, Cu, and Sb.

- A positive correlation has been demonstrated between Zn and Cd in Illinois coals by the IGS(9). These two elements are believed to be present in the host phase ZnS. Both Zn and Cd are removed with the Meyers Process, but only Zn removal was demonstrated by float-sink. Coals extracted by the Meyers Process generally exhibited a much higher rate of Zn removal than float-sink samples which could account for the accompanying increased number of samples exhibiting Cd removal. Because Cd is present in all of the tested coals in amounts less than 2 ppm, it is statistically difficult to observe the smaller changes in concentration that would be expected as the result of float-sink separation.

- Float-sink procedures were found to extract significant amounts of Li and F which were not removed to any significant degree by the Meyers Process.

- The elements As, Cr, Mn, Ni, and Zn were found amenable to removal by the Meyers Process in over 65% of the coals tested. The degree of extraction was found to vary from coal to coal, however, with As registering removals varying from 81-100%; Cr, 23-71%; Mn, 44-93%; Ni, 27-89%; and Zn, 47-95%. Ag, Cd, and Sb also appear to be effectively removed by the Meyers Process; but due to their low concentrations, the data are inconclusive.

- Float-sink procedures accounted for a larger number of elements being significantly removed. Again, the results were variable from coal to coal. Ag was found to be removed in the range 28-66%; As, 18-97%; Cr, 37-70%; Cu, 20-88%; F, 28-69%; Li, 33-72%; Mn, 20-96%; and Zn, 10-70%.

- The elements Pb and Cd were not removed from the coals using float-sink procedures. Sn also registered no losses. However, because of the large gains in Sn concentration found in the washed coals, it is suspected that contamination occurred during washing. This could be a result of Sn extracted from the soldered joints in the metal containers used in these separations by HCl present due to slight hydrolysis of the chlorinated float-sink solvents.
- Three mines (Mathies, Ken, and Delmont) showed the largest number of elements removed (14, 15 and 14, respectively).

In conclusion, the Meyers Process as well as float-sink procedures are potentially viable techniques for the removal of a number of potentially hazardous trace elements. This study indicates that Ag, As, Cd, Cr, Mn, Ni, Zn and Sb are removed by the Meyers Process in significant amounts for the majority of the coals tested. Float-sink procedures have been shown to also be useful for the reduction of Ag, As, Cr, Cu, F, Li, Mn and Zn in the majority of the coals tested. The effective removal of As, Cd, Cr, Sb, Ni, and Zn from coal is especially noteworthy, as these compounds are reportedly concentrated (along with Pb and Se) in the fine particulate emitted from coal-fired power plants(9-12). This fine particulate has been demonstrated to pass through conventional particulate control devices.

5.0 ACKNOWLEDGMENTS

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7.0 GLOSSARY OF ABBREVIATIONS AND SYMBOLS

Abbreviations

Abs	absolute
ASTM	American Society for Testing and Materials
btu	British Thermal Unit
cal	calories
eq	equation
Exp.	experiment
Kcal	kilocalories
ml	milliliter
ppm	parts per million
Rxn.	reaction
wt	weight

Symbols

C	concentration
Δ	difference in quantity following delta
μ	micron
$\underline{M}$	molarity
mM	millimole
$\underline{N}$	normality
P	total pressure, atmospheres
R	gas constant, cal/mole, ^{o}K
S	sulfur
S^{o}	elemental sulfur
S_{o}	organic sulfur
S_{p}	pyritic sulfur
S_{t}	total sulfur
SO_{4}	sulfate
σ	standard deviation
T	absolute temperature, ^{o}K
t	time, hours (leaching)-minutes (regeneration)
V	volume
W_{p}	pyrite concentration in coal, wt%
Y	ferric ion to total iron ratio

8.0 UNIT CONVERSION TABLE

To Convert From	To	Multiply By
btu	calories (cal)	252.0
feet (ft)	meters (m)	0.3048
gallons (gal)	liters	3.785
inches (in.)	centimeters (cm)	2.540
miles (mi)	kilometers (km)	1.609
ounces (oz)	grams (g)	28.35
pounds (lbs)	grams (g)	453.6
pounds (lbs)	kilograms (kg)	0.4536
square miles (sq.mi)	square kilometers (sq.km)	2.590
temp (^{o}F -32)	temp (^{o}C)	0.5556
tons	kilograms (kg)	907.200

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APPENDIX A

SEAM EXTENT AND SAMPLE LOCATION

A.1 Selection of Coals

Some of the background information which was utilized to aid in the selection of the twenty coals for this study is presented below in three paragraphs: Previous Production by State, Distribution of Coal Reserves and Distribution of Sulfur Content (4,5).

- Previous Production by State - Figure A-1 shows the percentage distribution of the cumulative production of coal in the United States up to January 1, 1967. In descending order of production, the six most productive states were: Pennsylvania, West Virginia, Illinois, Kentucky, Ohio and Indiana. These states have produced slightly over 84% of the coal consumed to date.
- Distribution of Coal Reserves in the United States - The distribution of the coal reserves in the United States is shown by Figure A-2, which gives aerial distribution and Figure A-3, which quantitatively describes the total resources remaining. From an examination of Figure A-3, it is apparent that coal from the following seven states would represent the vast majority of the remaining resources of bituminous coal in the United States: Illinois, West Virginia, Colorado, Pennsylvania, Kentucky, Ohio and Indiana.
- Distribution of Sulfur Content in Coal - Table A-1 shows the general distribution and average sulfur content of U.S. coals. This distribution shows that the major areas containing high sulfur coal are east of the Mississippi River.

TABLE A-1

AVERAGE SULFUR CONTENT OF U.S. COAL*

Coal Resources Determined by Mapping and Exploration	Low Sulfur (1.0% or Less)	Medium Sulfur (1.1-3.0%)	High Sulfur (>3%)
Total bituminous coal, subbituminous coal, and lignite	65%	15%	20%
Bituminous coal east of the Mississippi River	20%	37%	43%

*Dry basis.

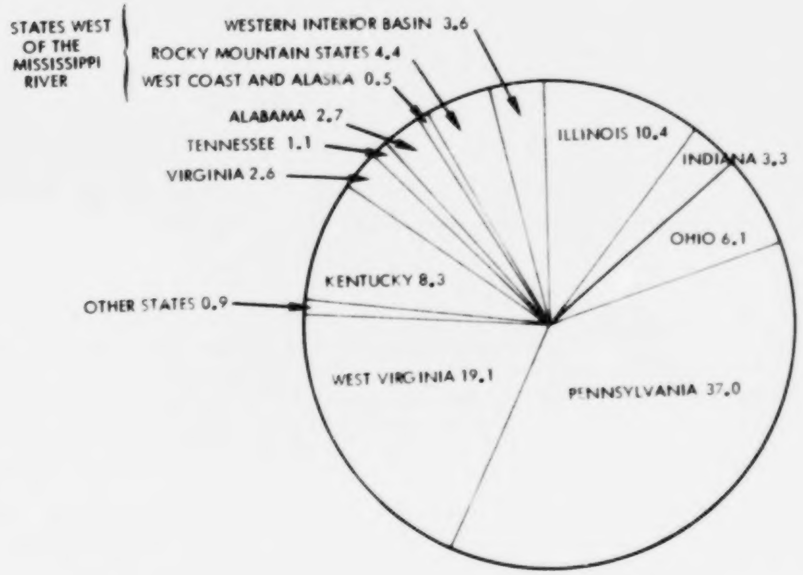


Figure A-1

Percentage Distribution of Cumulative Coal Production of the United States to 1 January 1967

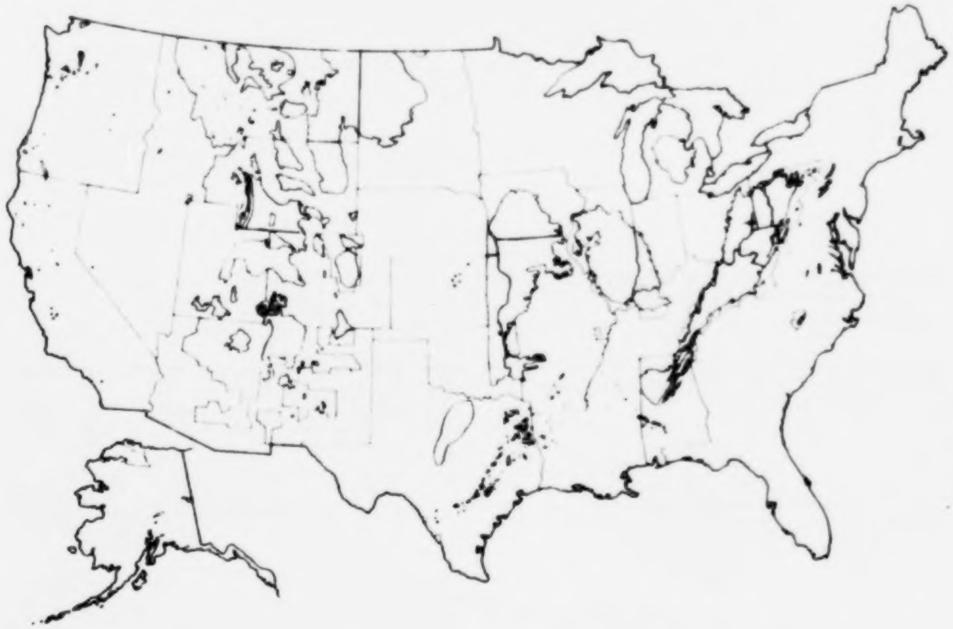
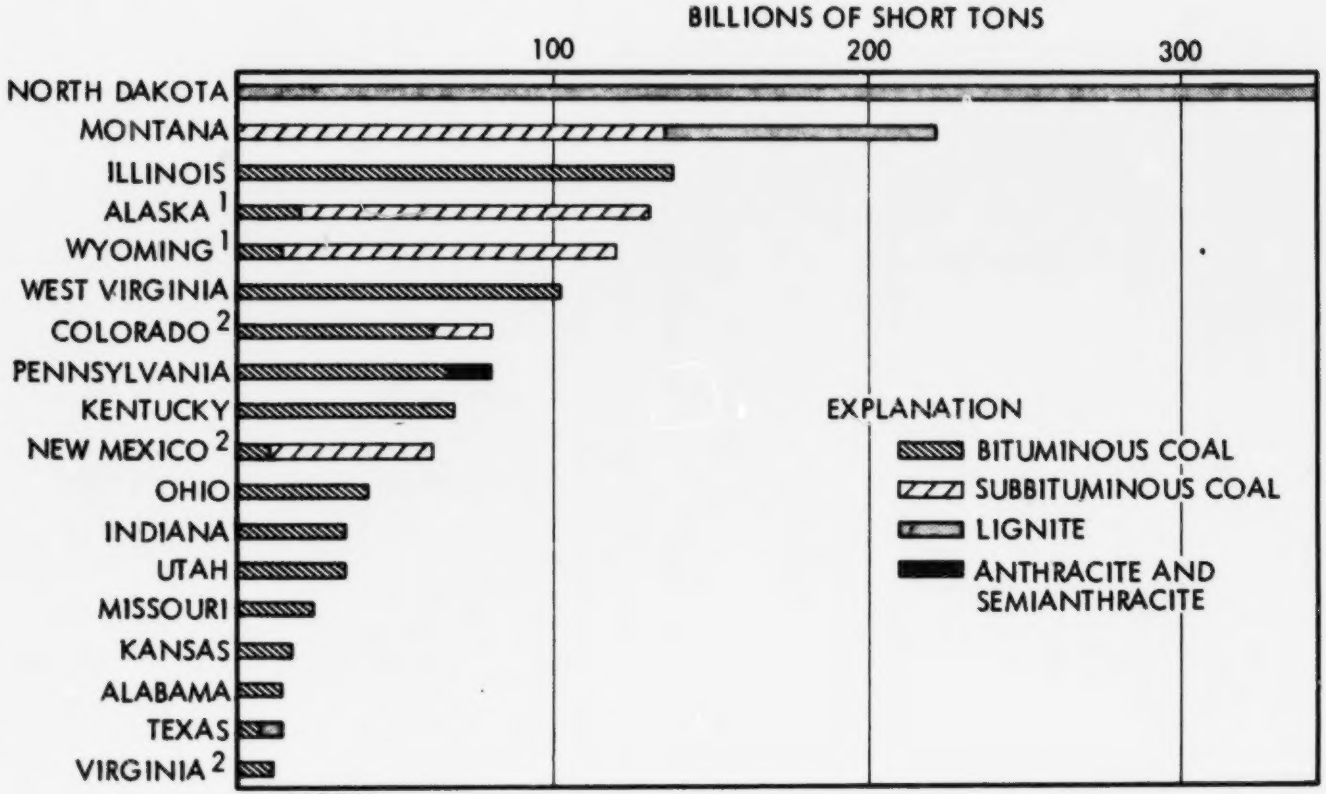


Figure A-2

Coal Fields of the Conterminous United States

Figure A-3

COAL RESOURCES OF THE UNITED STATES



NOTES:

1 SMALL RESOURCES OF LIGNITE INCLUDED WITH SUBBITUMINOUS COAL
2 INCLUDES ANTHRACITE IN QUANTITIES TOO SMALL TO SHOW ON SCALE OF DIAGRAM

A review of the average sulfur content of the states previously demonstrated to be of interest from a reserve or production point of view are listed below in Table A-2.

TABLE A-2

AVERAGE SULFUR CONTENT OF COALS BY STATE*

State	%S
● Colorado	0.56
● West Virginia	1.40
● Illinois	2.95
● Kentucky	2.22
● Ohio	3.52
● Indiana	3.00
● Pennsylvania	1.96

*Dry basis.

A.1.1 Coal Sample Selection(4,5)

APPALACHIAN COALS

Coals sampled, as noted in the following sections, are given in their descending stratigraphic order in the Monongahela, Conemaugh, and Allegheny stratigraphic groups, as defined in Pennsylvania and correlated with other beds of the Appalachian Region.

- Sewickley Seam - The Sewickley seam, most recent in geologic age of the coal beds investigated, is present in Pennsylvania (Greene, Butler, Clarion, Armstrong, Washington, Fayette, Westmoreland and Allegheny Counties), West Virginia (Marion, Monongalia, Wetzel, Marshall and Ohio Counties, where an estimated 2 billion tons remain), and Ohio, where the Sewickley correlates with the Meigs Creek (or No. 9) seam which is found in Monroe, Belmont, Harrison and Jefferson Counties. The Meigs Creek seam ranks third in production in Ohio. This initial survey initiated the examination of this coal with a sample from the Warwick mine in Greene County, Pennsylvania. Subsequently, a sample of this coal was taken at the Muskigum mine in Morgan County, Ohio. State maps showing the extent of this bed and the locations of the two mines are shown as Figures A-4, A-5 and A-6.

- Pittsburgh Seam - The Pittsburgh bed has been described as the most valuable individual mineral deposit in the United States. It is of minable thickness over an area of about 15,000 sq. km (6,000 sq. mi) in Pennsylvania (Washington, Greene, Indiana, Somerset, Allegheny, Armstrong, Westmoreland and Fayette Counties where approximately 7 billion tons remain), West Virginia (parts of Brooke, Ohio, Marshall, Wetzel, Monongalia, Marion, Doddridge, Harrison, Taylor, Preston, Mineral, Barbour, Upshur, Lewis, Gilmer, Braxton, Calhoun, Clay, Roane, Kanawha, Putnam, Mason, Cabell and Wayne Counties with approximately 10 billion tons of minable reserves), and eastern Ohio (primarily Belmont, Harrison, Jefferson, Carroll, Columbiana, Mahoning and Monroe Counties which contain some 10 billion tons of reserve). Pittsburgh coal is also found in the Georgis Creek basin (Garrett and Allegheny Counties, Maryland) where only about 2 million tons remain. A Pittsburgh coal from Greene County, Pennsylvania was examined in the previous bench-scale program(1). This program expanded the coverage of the Pittsburgh bed by sampling coals from: the Humphrey No. 7, Williams, Robinson Run, and Shoemaker mines in West Virginia; the Mathies and Isabella mines in Pennsylvania; and the Egypt Valley No. 21 and Powhattan No. 4 mines in Ohio. State maps showing the counties containing minable Pittsburgh coal and the locations of the mines sampled are shown in Figures A-7, A-8 and A-9. In this case, where the remaining reserves are rather clearly defined, the yearly production of the mines sampled represent approximately one two-thousandths of the seam reserve.

- Upper Freeport Seam - The Upper Freeport bed is less uniform in thickness than the overlying Pittsburgh bed or the underlying Lower Kittanning bed because it was subjected to local uplift and erosion before deposition of the overlying rocks. Nevertheless, it is a persistent bed throughout large areas in Pennsylvania, West Virginia, and Ohio, and is the third most important bed in the northern part of the Appalachian bituminous coal basin, both in production and in contained resources. In Pennsylvania, the Upper Freeport bed is thick and continuous in the counties around Pittsburgh and in the southwestern part of the state, where it ranges in thickness from 0.6 to 3 m (2 to 10 ft), and is 1 to 2 m (4 to 6 ft) thick over considerable areas. In West Virginia, the Upper Freeport bed is considered to be of minable thickness and purity over an area of 3,030 sq. km (1,165 sq. mi) in a belt running north-south through the central part of the state. In the northern part of the belt it ranges in thickness from 0.9 to 4 m (3 to 12 ft) and is 1 to 1.5 m (4 to 5 ft) thick over large areas. It thins to the south and is generally less than 0.6 m (2 ft) thick in Clay and Braxton Counties. In Ohio, the Upper Freeport bed is very irregular in thickness. It is locally as much as 2 m (8 ft) thick, but typically thins within a few miles, or tens of miles, to less than 35 cm (14 in.). Nevertheless, its wide distribution makes it the fourth most important bed in Ohio in known resources. The Marion and Delmont mines in Westmoreland

and Indiana Counties in Pennsylvania were sampled. State maps showing the location of these mines and the counties containing minable coal are shown in Figures A-10, A-11 and A-12.

- Lower Freeport (No. 6A) Seam - The Lower Freeport seam is also present in Pennsylvania, West Virginia, Ohio and Maryland. In Pennsylvania it is present in Lawrence, Beaver, Washington, Greene, Butler, Allegheny, Fayette, Westmoreland, Armstrong, Indiana, Somerset, Cambria, Bedford and Fulton Counties. In West Virginia, it is minable in parts of Nicholas, Roane, Braxton, Preston, Ohio, Brooke and Hancock Counties. Of the original 700 million tons minable in West Virginia, comparatively little has been removed. In Ohio the Lower Freeport is present and of importance in Jefferson, Athens, and Perry Counties where some 3 billion tons remain. In Maryland the Lower Freeport is mined in Garrett and Allegheny Counties in the northwest corner of the state bordering on West Virginia and Pennsylvania. For this program, a sample was taken from the Jane Mine in Pennsylvania. State maps showing the counties with minable Lower Freeport coal as well as the location of the mine sampled are shown in Figures A-13, A-14 and A-15. Since only two counties in Maryland are of concern, they are not mapped.

- Upper Kittanning Seam - The Upper Kittanning coal is stratigraphically the uppermost of the three Kittanning coals originally named at Kittanning, Pennsylvania. In Pennsylvania (Lawrence, Beaver, Washington, Greene, Fayette, Westmoreland, Armstrong, Clarion, Jefferson, Indiana, Somerset, Cambria and Clearfield Counties) the seam is thin and thus infrequently deep-mined. In West Virginia, the coal is of sufficient thickness for mining in parts of Kanawha, Nicholas, Clay, Braxton, Webster, Upshur, Lewis, Randoph, Barbour, Harrison, Taylor, Marion, Monongalia and Preston Counties over an area of some 3,600 sq. km (1400 sq. mi). The original reserves in West Virginia were estimated at 4 billion tons; and since this bed has not been a major producer for the state, the majority of the coal remains.

The Upper Kittanning seam is not a major coal bed in Ohio but geologically it follows the Lower Kittanning in its persistence from northeast to southwest in the Ohio coal fields. In Maryland, the Upper Kittanning seam is mined in both Garrett and Allegany Counties where it forms parts of the 1 billion tons of remaining coal reserves.

One sample for this program was taken from the Walker Mine in Maryland. State maps showing the extent of this bed are shown in Figures A-16, A-17, and A-18. (Maryland, where the sample was taken, is again not shown because of the two county representations.)

- Middle Kittanning or No. 6 Seam - This bed of coal is remarkably uniform and persistent and for many years was the most important coal bed in Ohio from the standpoint of quality and production. It is now outranked in production by the Pittsburgh (No. 8) bed, but is mined in every county along its outcrop from the Ohio-Pennsylvania state line and in Columbiana County on the north to Lawrence County on the south. This great coal bed is also important in Pennsylvania and West Virginia, and is tentatively correlated with the important Herrin (No. 6) coal of Illinois. Conservative estimates indicate well over 7 billion tons of No. 6 coal is over 0.9 m (28 in.) thick in Ohio.

  The coal is exceptionally firm and stands shipping well which, coupled with low ash often having high fusion temperature and a very low "free swelling index" (free burning), makes it an exceptional coal for the retail market. When it is mechanically cleaned and sized, it is an outstanding domestic stoker coal, free from troublesome "coke trees" and other operating difficulties. It is extensively used in the ceramic and cement industries owing to its superior performance under difficult operating conditions. For steam generation, it gives unusually good performance on chain or traveling grate stokers. Owing to its favorable ash softening temperature and burning characteristics it performs well in both multiple and single retort underfeed stokers.

  A single sample from this seam was taken from the Lucas Mine in Columbiana County, Ohio. State maps showing the location of this mine and the extent of the same are shown in Figures A-19, A-20, and A-21.

- Lower Kittanning Seam - The Lower Kittanning bed is most pervasive throughout the northern part of the Appalachian basin throughout portions of Pennsylvania, West Virginia, Ohio and Maryland. In Pennsylvania (Lawrence, Beaver, Washington, Greene, Fayette, Westmoreland, Butler, Clarion, Armstrong, Somerset, Indiana, Jefferson, Clearfield, Cambria, Bedford and Fulton Counties) it is widely strip mined. In West Virginia the Lower Kittanning (also called the No.5 Block) is minable in parts of Mingo, Logan, Boone, Wayne, Lincoln, Kanawha, Nicholas, Fayette, Clay, Roane, Braxton, Webster, Randolph, Upshur, Lewis, Barbour, Taylor, Marion, Monongalia, Preston and Mineral Counties. It covers an area greater than 6,700 sq. km (2600 sq. mi) and is estimated to have originally contained over 10 billion tons. Though one of the most mined beds of West Virginia, much of this reserve remains. This coal is present in most of the counties comprising the coal fields of eastern Ohio, extending from Mahoning County in the northeast through Lawrence and Scioto Counties in the southeast. In Ohio, the estimated minable reserves total three billion tons. The coal is also present in the two coal counties of Maryland (unmapped), though this is not of major commercial importance.

The previous bench scale program(1) examined a Lower Kittanning coal from Indiana County, Pennsylvania. For this program, samples were obtained from the Fox and Bird No. 3 mines in Pennsylvania and the Martinka mine in West Virginia. State maps showing the extent of this bed and the mine locations are given in Figures A-22, A-23, and A-24.

- Clarion or No. 4A Seam - The Clarion coal can be traced from the Ohio-Pennsylvania line southwest to the Ohio River. However, along most of this line of outcrop the bed is too thin to be worked. The one deposit of importance lies in the southern part of the state and includes northern Lawrence, eastern Scioto, eastern Jackson, northwestern Gallia, and southern Vinton Counties. In places the coal lies directly below the Vanport lime but elsewhere is separated by two partings of clay. This varies, however, and especially so along the margin of the field. The thickness of the bed in Southern Ohio is 10.9 to 1.2 m (3 to 4 ft) thick. The Clarion coal is moderate in heating value, high in sulfur and ash.

  Clarion coal when washed is a very suitable industrial coal for steam generation utilizing underfed stokers, pulverized fuel furnaces, chain or traveling grate stokers, and spreader stokers. The most desirable feature of this coal for steam use is the wide ash fusion range, as the fusion starts at an initial 2150°F, with the softening temperature 2280°F and the ash fluid temperature at 2560°F. This fusion range makes it a relatively safe coal to use on stokers.

  A sample from this seam was taken from the Meigs mine in Meigs County, Ohio. A state map showing the location of this mine is shown in Figure A-25.

- Dean Seam - The Dean seam, more commonly known as Big Mary seam, has its most important development in the New River area of Anderson, Campbell, and Morgan Counties in Tennessee. Mining thicknesses in this area range from 0.9 to 3 m (36 in. to 10 ft) or more. The roof is a strong gray shale unusually subject to air slacking, while the bottom is a soft shale or clay. The Big Mary seam commonly occurs in two benches; and in the thinner seam areas, only the upper bench is evident. The lower bench may vary from 0.2 to 0.7 m (10 in. to 30 in.) in thickness and occurs below the top bench with an interval of from several inches to 1.5 m (5 ft) or more. Occasionally, the two benches join to form a thick seam. The coal from the Big Mary vein is coarse and blocky. It is suitable for general steam and domestic use and was formerly a favorite railroad fuel. A single sample was taken from the Dean mine in Scott County, Tennessee.

- Mason Seam - To provide an example of an Eastern Kentucky coal, a sample was taken from the Dixie Fuel Company's No. 1 mine in Harlan County, Kentucky. A state map showing the location of the sampling point in the Upper Cumberland reserve district is shown in Figure A-26.

- Campbell Creek Seam - A domestic steam, gas, by-product, and metallurgical coal named for its occurrence along Campbell Creek, Kanawha County, West Virginia. It is minable in parts of Wayne, Mingo, Wyoming, McDowell, Logan, Lincoln, Boone, Raleigh, Fayette, Kanawha, Nicholas, Clay, and Calhoun Counties in West Virginia over an area of about 5,400 sq. km (2,100 sq. mi); it is the most important seam of the entire Pottsville Group, the original minable tonnage estimated as having been about 8 billion tons. The coal is generally a multiple-bedded gas and splint type coal; it is 0.6 to 3 m (2 to 10 ft) thick, averaging perhaps 1.5 m (5 ft). It occurs 11 to 29 m (37 to 95 ft) above the Powellton coal. A sample of this seam was taken from the Kopperston No. 2 mine in Wyoming County, West Virginia.

- Eagle Coal Seam - A domestic steam, by-product and coking coal named for Eagle, West Virginia, where it was first mined. It is minable in parts of McDowell, Mingo, Wyoming, Boone, Raleigh, Kanawha, Fayette, Nicholas, Clay, Webster, Braxton, Upshur, and Randolph Counties in West Virginia over an area of 3,500 sq. km (1,360 sq. mi); the original minable tonnage is estimated to have been nearly 4.2 billion tons. The coal is double-to-multiple-bedded and splinty and ranges from 0.6 to 3 m (2 to 10 ft) thick, averaging perhaps 1.2 m (4 ft). A sample of this bed was taken from the Harris Nos. 1 and 2 mines in Boone County, West Virginia.

- Corona Seam - In Alabama the Pratt Coal Group ranks second only to the Mary Lee Group from a tonnage standpoint and includes the American (Nickel Plate), Curry, Gillespie and Pratt (Corona) beds mined in Jefferson and Walker Counties. The principal beds in this group are the Pratt (known in the western part of the basin as the Nickel Plate). Thickness of the Pratt bed varies from 0.9 to 1.7 m (2 ft 10 in. to 5-1/2 ft); an average of 26 sections of this bed shows 1.7 m (5-1/2 in.) of coal, 63 cm (2-1/2 in.) of parting and 0.9 m (34 in.) of coal. Roof and floor of the Pratt bed usually are sandstone. This bed is one of the major sources of coking coal in Alabama. The Corona, which ranges from 0.8 to 1.2 m (30 to 52 in.) in thickness, probably is the western extension of the Pratt bed. A single sample was taken from the North River mine in Jefferson County, Alabama.

EASTERN INTERIOR REGION

- No. 5 Bed (Ill.), or No. 9 (Ky.) Seam - The No. 5 bed is the most widespread and commercially valuable coal bed in the Eastern Interior coal basin. It is known in Illinois as the No. 5 Harrisburg or Springfield bed; in Indiana as the Springfield or No. V bed; and in western Kentucky as the No. 9 bed. It is of minable thickness over an area of about 52,000 sq. km (20,000 sq. mi) in the three states and it is recognizable as a lithologic unit over an area of about 78,000 sq. km (30,000 sq. mi). In southeastern Illinois, it is 1 to 1.5 m (4 to 5 ft) thick over large areas; in Indiana it has an average thickness of 1.5 m (5 ft) and locally is as much as 3 m (11 ft) thick throughout its area of occurrence. From the standpoint of resources, it is the most important bed in Indiana and western Kentucky, and it is second only to the Herrin No. 6 bed in Illinois.

  In Illinois the No. 5 bed is present in strippable quantities in some fifty counties having more than forty-one billion tons of reserves. In Indiana, the Springfield (No. V) bed is present in Sullivan, Vigo, Knox, Greene, Daviess, Pike, Gibson, Posey, Vanderburgh and Warrick Counties, which contain twenty-six billion tons of reserve.

  The correlating coal seam in western Kentucky (the No. 9 bed) is commonly found throughout the entire reserve district and presently may be mined in Butler, Daviess, Henderson, Hopkins, Muhlenberg, Ohio, Union, or Webster Counties.

  A previous program(1) utilized a No. 5 coal from Fulton County, Illinois. This survey program has obtained samples from the Eagle No. 2 mine in Gallatin County, Illinois. In Kentucky, samples were taken from the Camp Nos. 1 and 2 mines in Union County, the Ken mine in Ohio County and the Star mine in Hopkins County. State maps showing the extent of these beds are shown in Figures A-27, A-28, and A-29.

- Herrin No. 6 Bed (Ill.), No. 11 (Ky.) Seam - The Herrin No. 6 bed is recognizable over an area of about 29,000 sq. km (15,000 sq. mi) in the Eastern Interior coal basin, where it is second in commercial importance only to the No. 5 bed. It is known in western Kentucky as the No. 11 bed and in Indiana as the Hymera or No. VI bed. This coal attains maximum thickness in southern Illinois, where it is locally as much as 4 m (14 ft) thick. In central Illinois and in western Kentucky, the Herrin (No. 6) bed is 1.5 to 2 m (5 to 7 ft) thick over large areas. It thins eastward and is relatelv unimportant in Indiana. It also thins toward the northwest edge of the basin. From the standpoint of resources and production, it is the most important coal in Illinois. In Illinois, the No. 6 bed has reserves in fifty-six counties, totalling approximately sixty-six billion tons. In Kentucky, the No. 11 bed is presently being mined in Hopkins, Ohio and Muhlenberg Counties. Indiana's equivalent Hymera (No. VI) bed is of lesser importance but it occurs in minable thickness in Sullivan, Knox, Pike, Gibson, Warrick, Vanderburgh and Posey Counties.

The previous bench-scale program(1) utilized a No. 6 coal from Randolph County, Illinois and the present program examined samples of No. 6 coal from the Orient No. 6 mine in Jefferson County, Illinois and from the Homestead mine in Ohio County, Kentucky. State maps showing the extent of minable beds and the mine locations are shown in Figures A-30, A-31, and A-32.

WESTERN INTERIOR REGION

- Des Moines No. 1 Seam - To provide a sample of coal from the Western Interior Region, an Iowa coal from Marion County (the Des Moines No. 1) seam was selected. Iowa's total reserves are an estimated 7 billion tons.

WESTERN COAL REGION

- Wadge Seam - The Wadge seam of the Yampa field in the Green River region is an example of coals from the northwestern part of Colorado. The Edna mine in Routt County was sampled. The Wadge seam in Colorado correlates with other coals of the Green River region mined in the Rock Springs area in southwestern Wyoming. In Colorado, the reserves are estimated at some one and one-half billion tons.
- No. 6, 7 and 8 Seams (Fruitland Formation) - The No. 6, 7 and 8 seams of the Fruitland Formation are presently being mined by one of the largest stripping operations in the nation at the Navajo mine in San Juan County, New Mexico. The coal resources of New Mexico are estimated at 62 billion tons, 80% of which are subbituminous coals which include the coal mined at the Navajo mine.
- Roland-Smith Seam - The Roland-Smith seam of the Powder River Region represents one of the largest strippable reserve areas of subbituminous coal in the U.S. For this program a sample of the seam was taken from the Belle Ayr mine in Campbell County (center of the Powder River Region), Wyoming.
- Rosebud Seam - The Rosebud seam of subbituminous coal is representative of the vast reserves (20 billion tons) of strippable coal available in the Fort Union Region of Eastern Montana. This region is represented in northeastern Wyoming by the coals of the Powder River Region and translates into the lignites of eastern Montana and western North Dakota. For the survey program, a sample was taken from a large mine in the area, the Colstrip mine in Rosebud County, Montana.

A.1.2 Mine Sample Procedures

The following tabulation describes in detail the specific sampling procedures used in the twenty additional mines sampled in this part of the program. The procedures for the initial fifteen coals were documented previously(3).

- Muskingum Mine, Meigs Creek No. 9 Seam, Morgan County, Ohio, Central Ohio Coal Company. The raw run of the mine coal was collected over a 4 hour period on September 17, 1973. One hundred and forty-four increments totaling 908 kg (2000 lbs) were taken by stopped belt sampling as the coal was going to the preparation plant.

- Powhattan No. 4 Mine, Pittsburgh No. 8 Seam, Monroe County, Ohio, Quarto Mining Company. The raw run of the mine coal sample was collected over a 3-3/4 hour period of September 18, 1973. One hundred and forty-eight increments totaling 908 kg (2000 lbs) were taken from a stopped belt leading from the stock pile to the tipple.

- Isabella Mine, Pittsburgh Seam, Fayette County, Pennsylvania, National Mines Corporation. The raw run of mine sample was collected over a 3-1/2 hour period on November 21, 1973. One hundred and forty-eight increments totaling 908 kg (2000 lbs) were taken from a stopped belt leading from the mine to the preparation plant.

- Mathies Mine, Pittsburgh Seam, Washington County, Pennsylvania, Mathies Coal Company. The raw run of mine sample was collected over a 4 hour period on July 23, 1973. Ninety increments totaling 908 kg (2000 lbs) were taken from a stopped belt leading from the mine to the coal preparation plant.

- Robinson Run Mine, Pittsburgh Seam, Harrison County, West Virginia, Consolidation Coal Company. The raw run of the mine coal sample was collected over a 4 hour period on September 19, 1973. One hundred and forty-four increments totaling 908 kg (2000 lbs) were taken from a stopped belt leading to the preparation plant.

- Williams Mine, Pittsburgh Seam, Marion County, West Virginia, Consolidated Coal Company, Mountaineer Coal Company Division. The raw run of mine coal sample was collected over a 6-3/4 hour period on September 20, 1973. Sixty-six 30 lb increments totaling 908 kg (2000 lbs) were taken from a stopped belt leading to the preparation plant.

- Shoemaker Mine, Pittsburgh Seam, Marshall County, West Virginia, Consolidation Coal Company, Mountaineer Coal Company Division. The raw run of mine sample was collected over a 4 hour period on September 19, 1973. One hundred and forty-eight increments totaling 908 kg (2000 lbs) were taken from a stopped belt leading from the mine to the preparation plant.

- Marion Mine, Upper Freeport Seam, Indiana County, Pennsylvania, Tunnelton Mining Company. The raw run of mine coal was collected over a 4-1/2 hour period on July 23, 1973. Sixty increments totaling 908 kg (2000 lbs) were taken by stopped belt sampling as the coal was going into the silo.

- Delmont Mine, Upper Freeport Seam, Westmoreland County, Pennsylvania, Eastern Associated Coal Corporation. The raw run of mine coal sample was collected over a 5 hour period on September 21, 1973. One hundred and sixty increments totaling 908 kg (2000 lbs) were taken from a stopped belt leading to the preparation plant.

- Lucas Mine, Middle Kittanning Seam, Columbiana County, Ohio, Buckeye Coal Mining Company. The raw run of mine sample was collected over a 5 hour period on July 24, 1973. Sixty increments totaling 908 kg (2000 lbs) were collected from fifteen locations in the raw coal pit.

- Martinka Mine, Lower Kittanning Seam, Logan County, West Virginia, American Electric Power Company. The raw run of mine sample was taken during a 3-1/2 hour period on May 2, 1974. One hundred and forty-seven increments totaling 908 kg (2000 lbs) were taken from a stopped belt.

- Bird No. 3 Mine, Lower Kittanning Seam, Somerset County, Pennsylvania, Island Creek Coal Company. The raw run of mine sample was taken over a 3-1/2 hour period on September 21, 1973. One hundred and sixty-six increments totaling 908 kg (2000 lbs) were taken from a stopped belt leading to the tipple and before the coal from the No. 2 and No. 3 mines were blended.

- Meigs Mine, Clarion 4A Seam, Meigs County, Ohio, American Electric Power Company. The raw run of mine sample was collected over a 3-1/2 hour period on September 17, 1973. One hundred and forty increments totaling 908 kg (2000 lbs) were taken from a stopped belt leading to the stockpile.

- Dean Mine, Dean Seam, Scott County, Tennessee, Royal Dean Coal Company. The raw run of mine sample was collected over a 4 hour period on January 17, 1974. Approximately 55 increments totaling 908 kg (2000 lbs) were taken from a stopped belt leading from the mine to the stockpile.

- Kopperston No. 2 Mine, Campbell Creek Seam, Wyoming County, West Virginia, Eastern Associated Coal Corporation. The raw run of mine sample was collected over a 4 hour period on November 26, 1973. One hundred sixty increments totaling 908 kg (2000 lbs) were taken from a moving belt leading from the mine to the preparation plant.

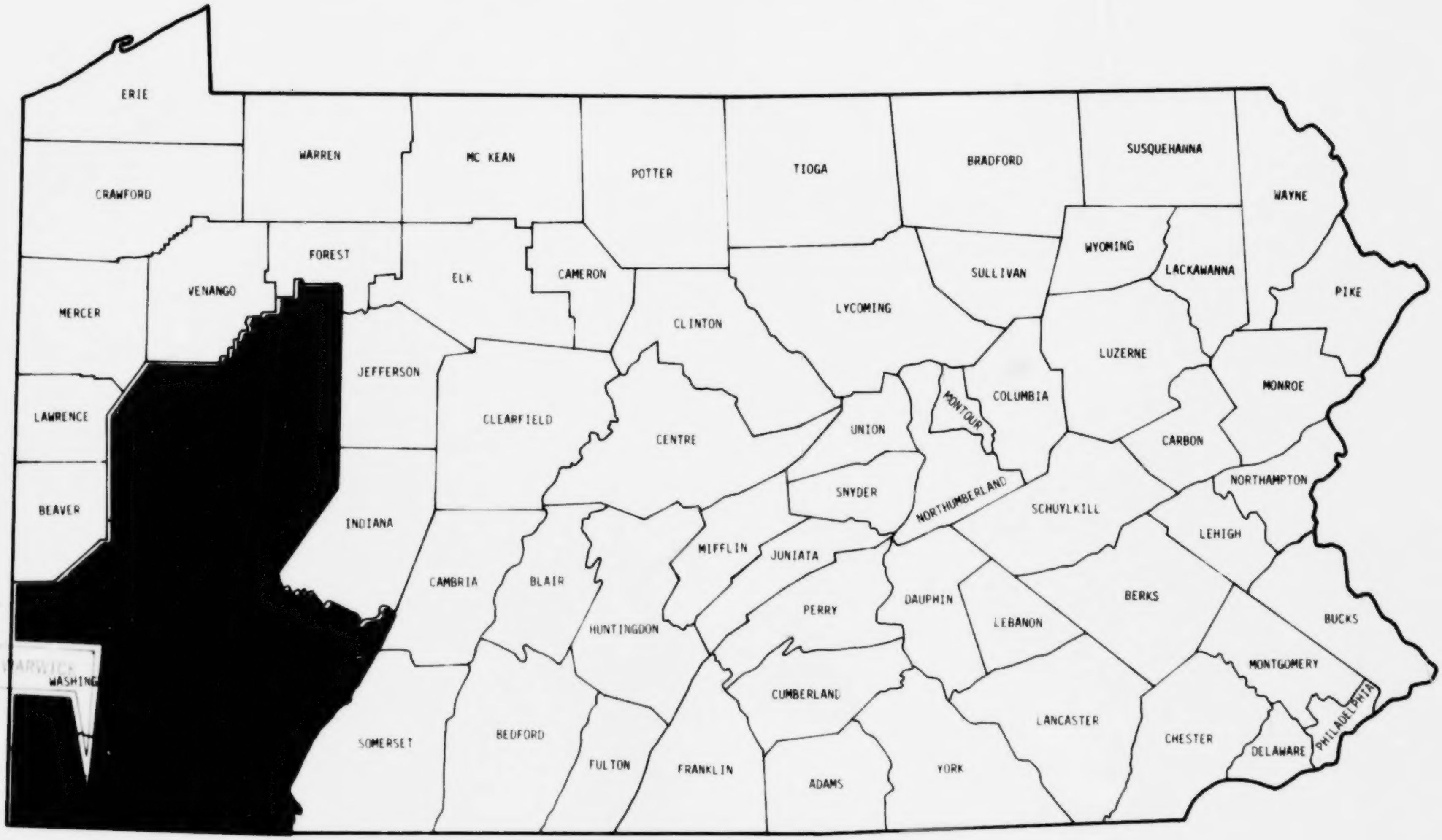
- Harris Nos. 1 and 2 Mines, Eagle and No. 2 Gas Seams, Boone County, West Virginia, Eastern Associated Coal Corporation. The raw run of mine sample was collected over a 4 hour period on November 26, 1973. One hundred and forty increments totaling 908 kg (2000 lbs) were taken from mine cars coming directly from the mine.

- North River Mine, Corona Seam, Jefferson County, Alabama, Republic Steel Corporation. The raw run of mine sample was taken on May 23, 1974. Fifty 40 lb increments totaling 908 kg (2000 lbs) were taken from various locations in the stockpile.

- Homestead Mine, No. 11 Seam, Ohio County, Kentucky, Peabody Coal Company. The raw run of mine sample was collected over a 4 hour period on December 11, 1973. An automatic sampler was used to take 30 increments totaling 908 kg (2000 lbs).

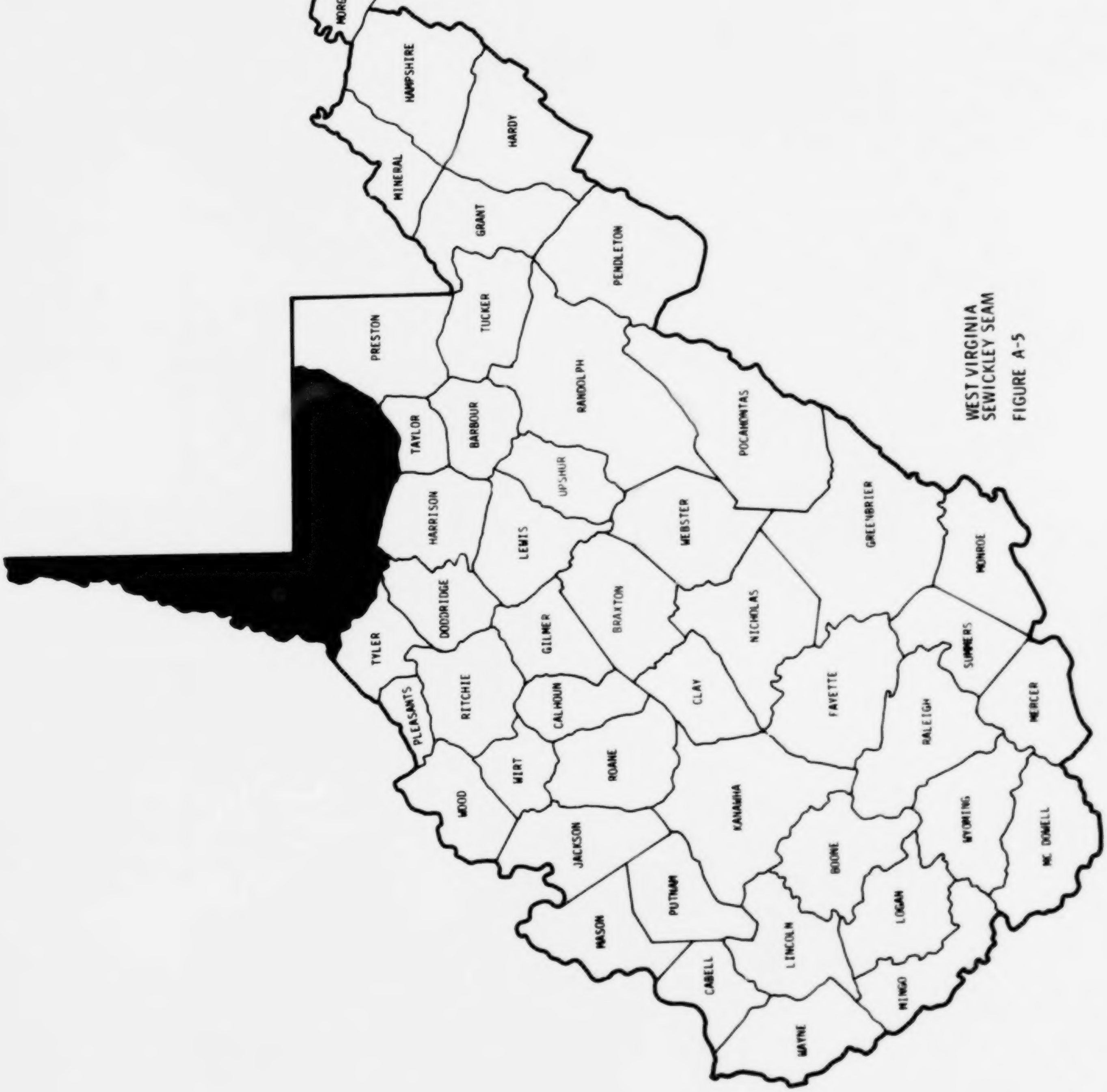
- Ken Mine, No. 9 Seam, Ohio County, Kentucky, Peabody Coal Company. The raw run of mine sample was collected over a 4-1/4 hour period on December 12, 1973. An automatic sampler was used to take 30 increments totaling 908 kg (2000 lbs).

- Star Mine, No. 9 Seam, Hopkins County, Kentucky, Peabody Coal Company. The raw run of mine sample was collected over a 4 hour period on December 13, 1973. Approximately 30 increments totaling 908 kg (2000 lbs) were taken at the primary cut of an automatic sampler.


ERIE
WARREN
MC KEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
CRAWFORD
FOREST
ELK
CAMERON
CLINTON
LYCOMING
SULLIVAN
WYOMING
LACKAWANNA
PIKE
MERCER
VENANGO
JEFFERSON
CLEARFIELD
CENTRE
UNION
MONTOUR
COLUMBIA
LUZERNE
MONROE
CARBON
LAWRENCE
BEAVER
INDIANA
SNYDER
NORTHUMBERLAND
SCHUYLKILL
NORTHAMPTON
LEHIGH
CAMBRIA
BLAIR
MIFFLIN
JUNIATA
HUNTINGDON
PERRY
DAUPHIN
LEBANON
BERKS
BUCKS
MONTGOMERY
WARWICK
WASHING
SOMERSET
BEDFORD
FULTON
FRANKLIN
CUMBERLAND
ADAMS
YORK
LANCASTER
CHESTER
DELAWARE
PHILADELPHIA

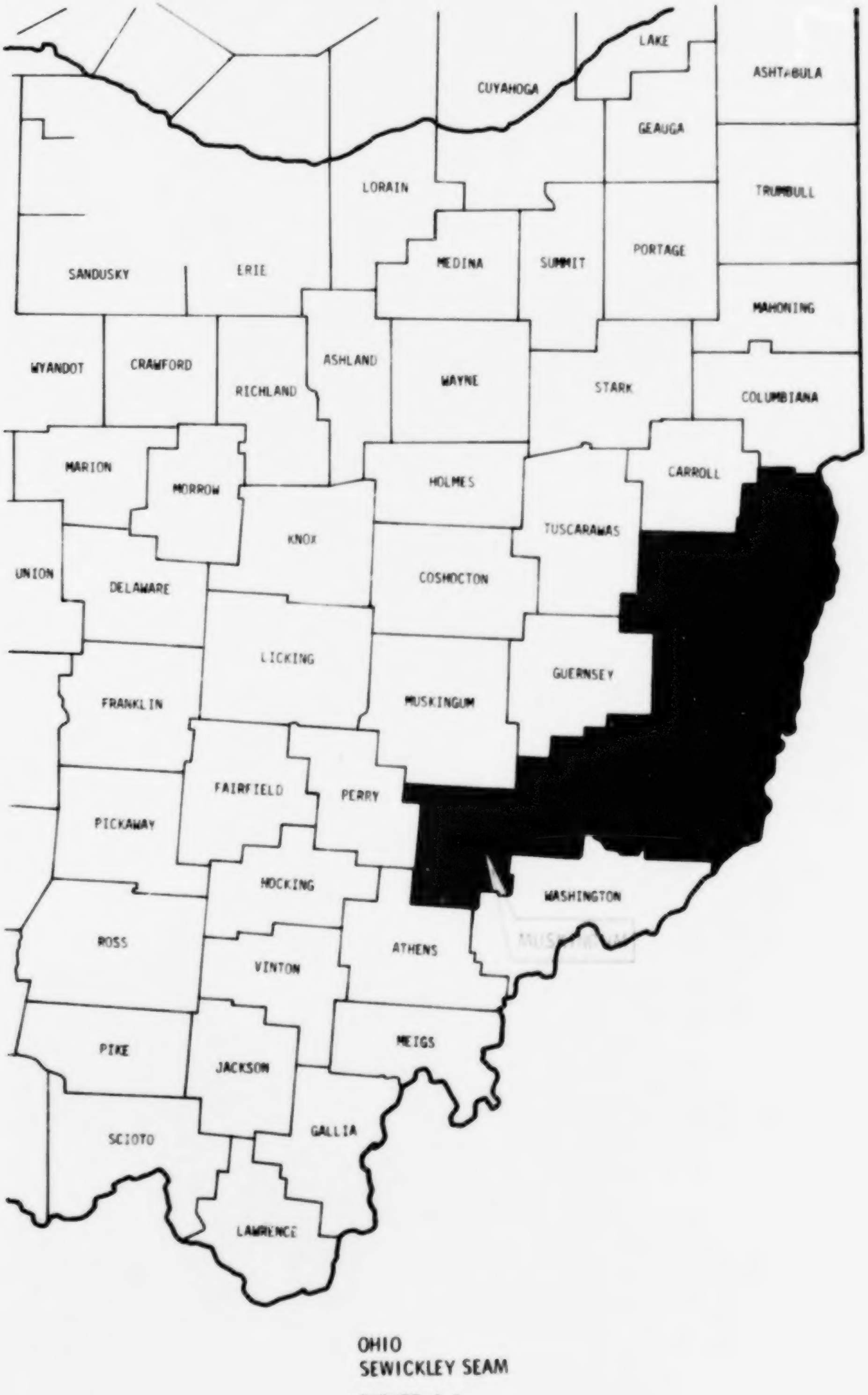
PENNSYLVANIA
SEWICKLEY SEAM

FIGURE A-4


JEFFERSON
BERKELEY
MORGAN
HAMPSHIRE
MINERAL
HARDY
GRANT
PENDLETON
TUCKER
PRESTON
TAYLOR
BARBOUR
RANDOLPH
POCAHONTAS
UPSHUR
HARRISON
LEWIS
WEBSTER
GREENBRIER
MONROE
DODDRIDGE
TYLER
GILMER
BRAXTON
NICHOLAS
SUMMERS
RITCHIE
PLEASANTS
CALHOUN
CLAY
FAYETTE
RALEIGH
MERCER
WIRT
ROANE
WOOD
JACKSON
KANAWHA
BOONE
WYOMING
MC DOWELL
MASON
PUTNAM
LOGAN
LINCOLN
CABELL
MINGO
WAYNE

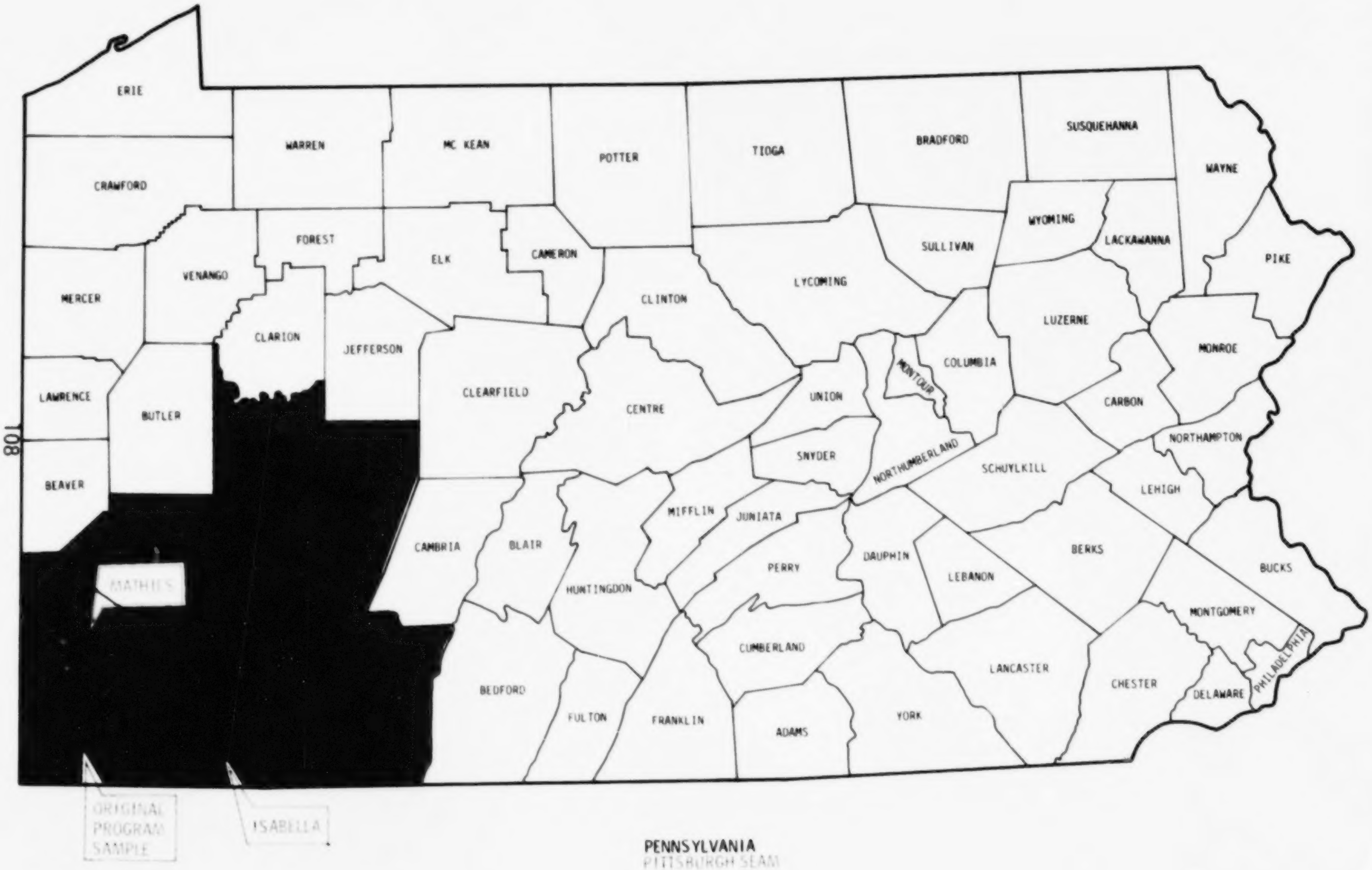
WEST VIRGINIA
SEWICKLEY SEAM

FIGURE A-5


LAKE
ASHTABULA
CUYAHOGA
GEAUGA
TRUMBULL
LORAIN
MEDINA
SUMMIT
PORTAGE
SANDUSKY
ERIE
MAHONING
WYANDOT
CRAWFORD
ASHLAND
RICHLAND
WAYNE
STARK
COLUMBIANA
MARION
MORROW
HOLMES
CARROLL
KNOX
TUSCARAWAS
UNION
DELAWARE
COSHOCTON
LICKING
GUERNSEY
FRANKLIN
MUSKINGUM
FAIRFIELD
PERRY
PICKAWAY
HOCKING
WASHINGTON
ROSS
ATHENS
VINTON
PIKE
MEIGS
JACKSON
GALLIA
SCIOTO
LAWRENCE

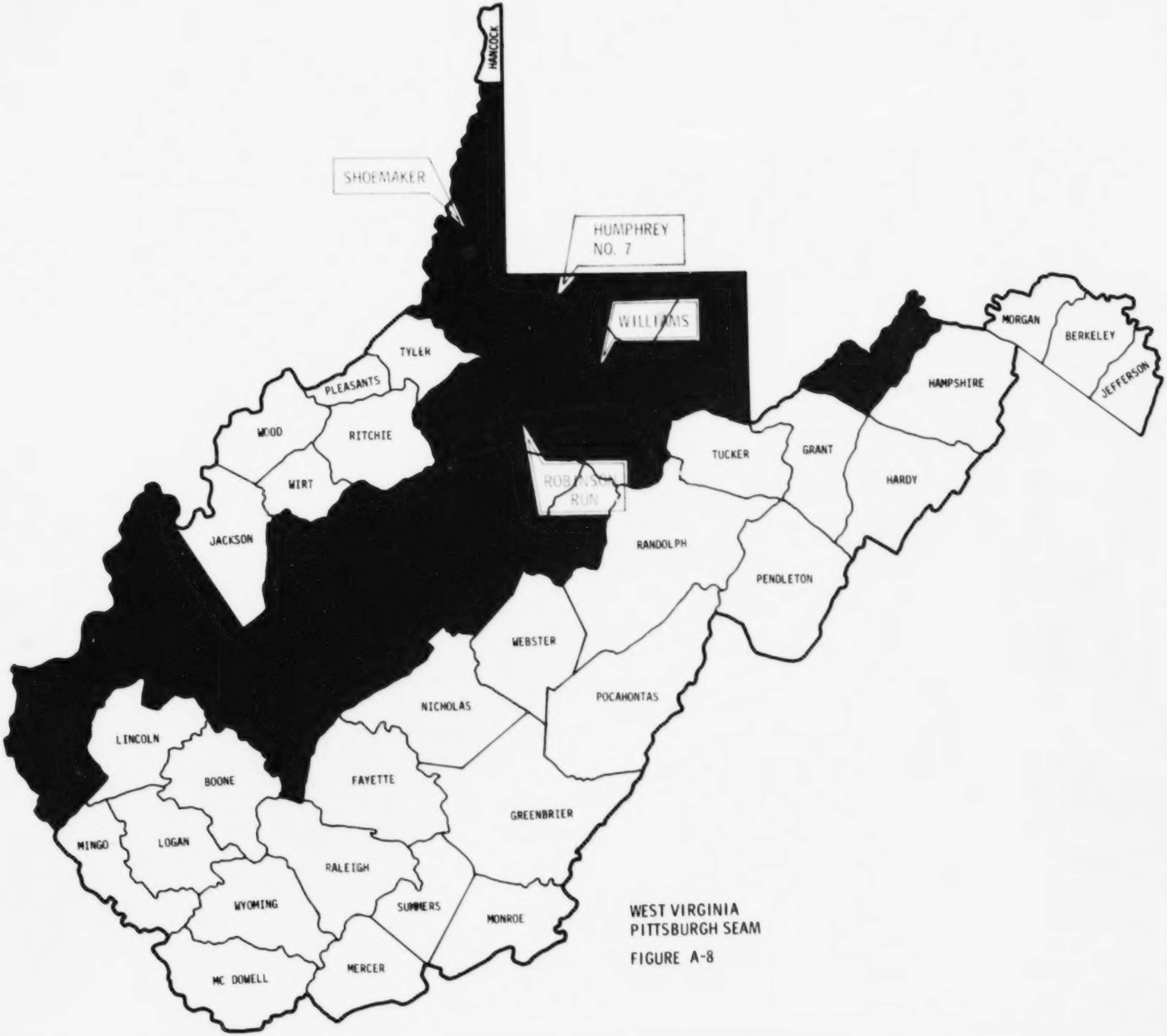
OHIO
SEWICKLEY SEAM

FIGURE A-6


ERIE
WARREN
MC KEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
CRAWFORD
FOREST
ELK
CAMERON
SULLIVAN
WYOMING
LACKAWANNA
PIKE
MERCER
VENANGO
CLINTON
LYCOMING
LUZERNE
CLARION
JEFFERSON
COLUMBIA
MONROE
MONTOUR
LAWRENCE
BUTLER
CLEARFIELD
CENTRE
UNION
CARBON
NORTHAMPTON
BEAVER
SNYDER
NORTHUMBERLAND
SCHUYLKILL
LEHIGH
MIFFLIN
JUNIATA
CAMBRIA
BLAIR
BERKS
BUCKS
MATHIES
DAUPHIN
PERRY
HUNTINGDON
LEBANON
MONTGOMERY
PHILADELPHIA
CUMBERLAND
LANCASTER
CHESTER
DELAWARE
BEDFORD
FULTON
FRANKLIN
ADAMS
YORK
ORIGINAL PROGRAM SAMPLE
ISABELLA

PENNSYLVANIA
PITTSBURGH SEAM

FIGURE A-7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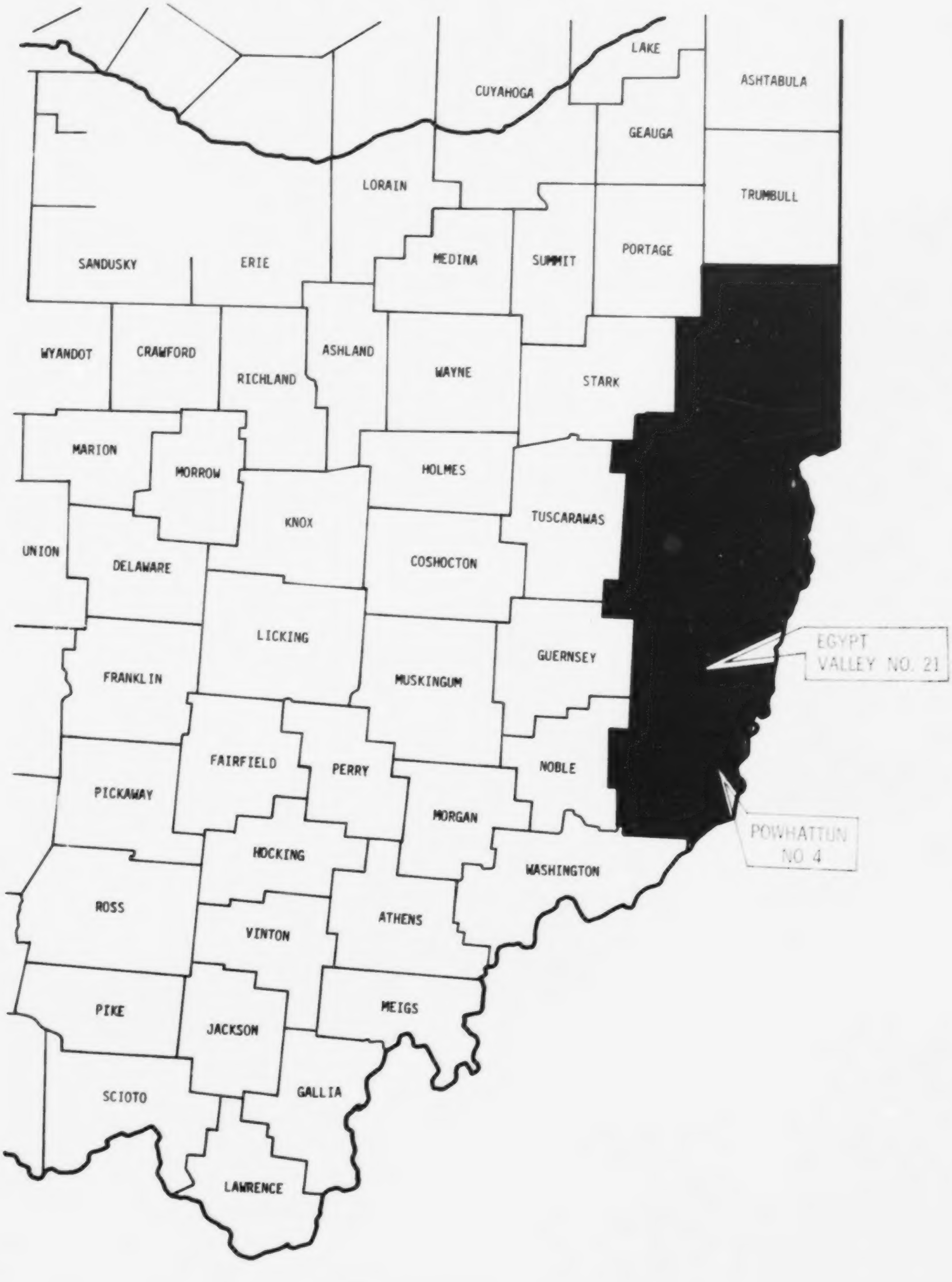
SHOEMAKER
HUMPHREY NO. 7
WILLIAMS
ROBINSON RUN
TYLER
PLEASANTS
WOOD
RITCHIE
WIRT
JACKSON
LINCOLN
BOONE
MINGO
LOGAN
WYOMING
MC DOWELL
RALEIGH
MERCER
SUMMERS
MONROE
FAYETTE
NICHOLAS
GREENBRIER
WEBSTER
POCAHONTAS
RANDOLPH
PENDLETON
TUCKER
GRANT
HARDY
HAMPSHIRE
MORGAN
BERKELEY
JEFFERSON

WEST VIRGINIA
PITTSBURGH SEAM

FIGURE A-8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CUYAHOGA
GEAUGA
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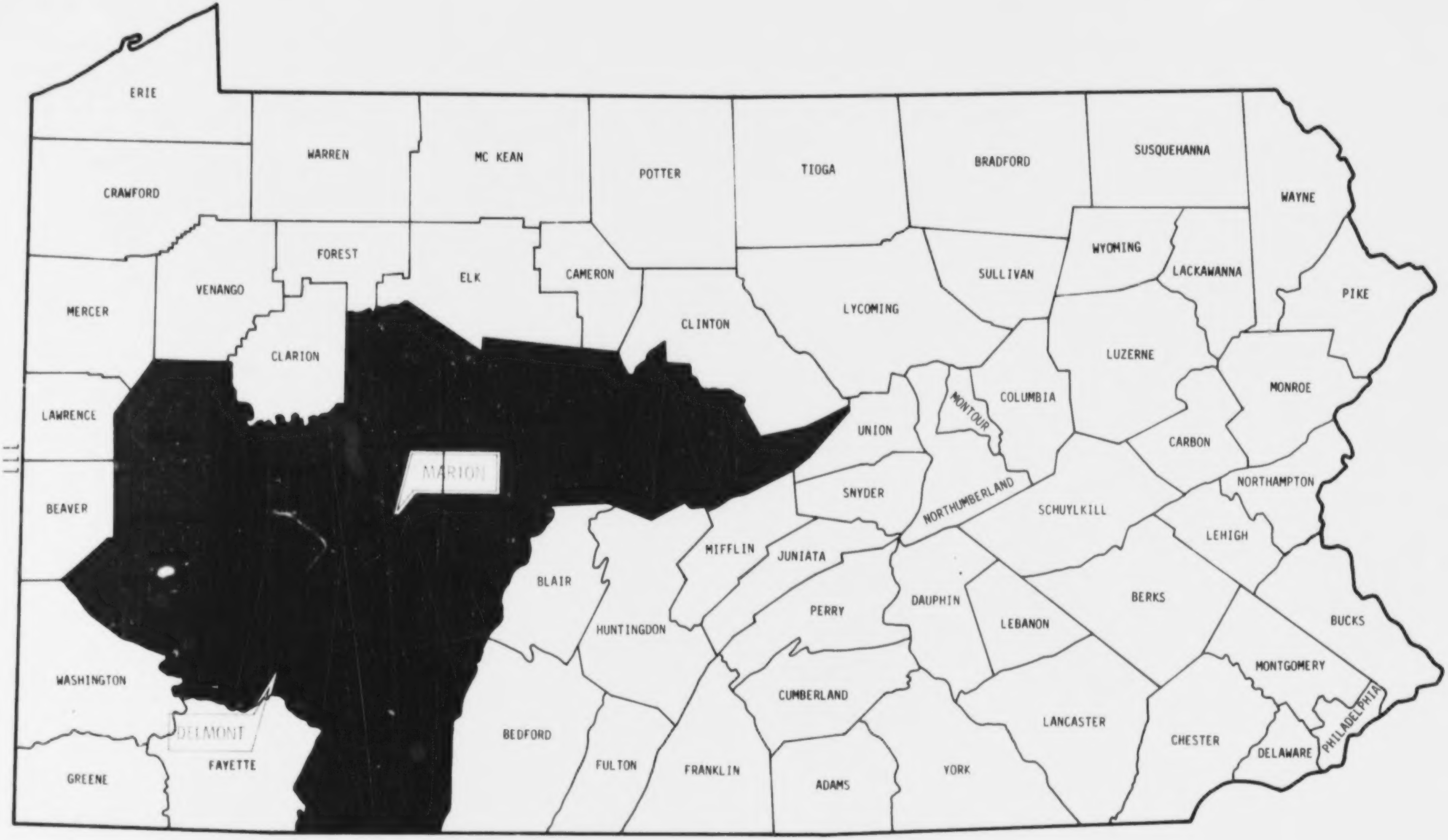
TRUMBULL
SANDUSKY
ERIE
MEDINA
SUMMIT
PORTAGE
WYANDOT
CRAWFORD
RICHLAND
ASHLAND
WAYNE
STARK
MARION
MORROW
HOLMES
KNOX
TUSCARAWAS
UNION
DELAWARE
COSHOCTON
LICKING
GUERNSEY
EGYPT VALLEY NO. 21
FRANKLIN
MUSKINGUM
FAIRFIELD
PERRY
NOBLE
PICKAWAY
MORGAN
POWHATTUN NO 4
HOCKING
WASHINGTON
ROSS
ATHENS
VINTON
PIKE
MEIGS
JACKSON
SCIOTO
GALLIA
LAWRENCE

OHIO
PITTSBURGH SEAM

FIGURE A-9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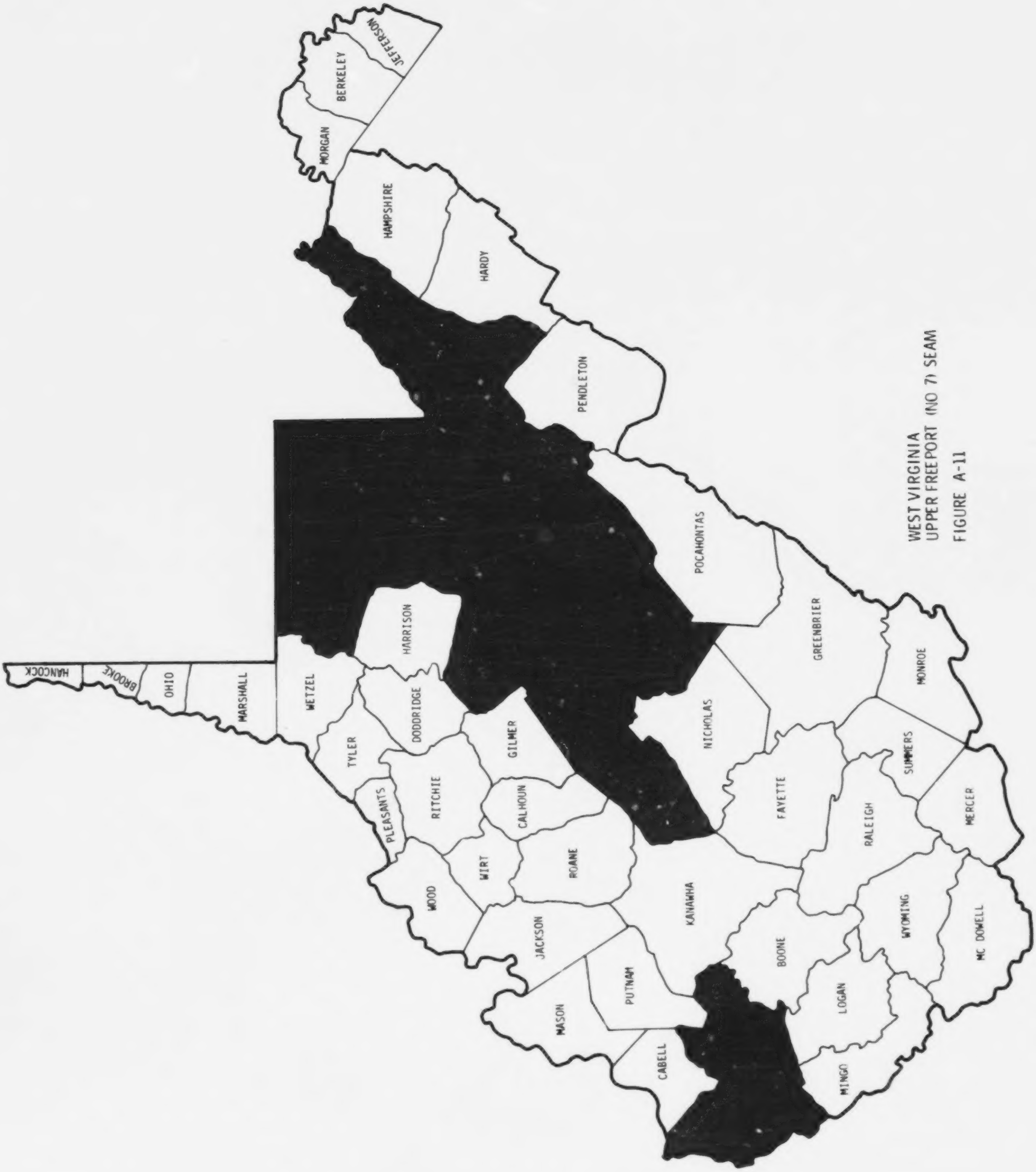
MC KEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
CRAWFORD
FOREST
ELK
CAMERON
WYOMING
LACKAWANNA
PIKE
MERCER
VENANGO
CLINTON
LYCOMING
SULLIVAN
CLARION
LUZERNE
MONROE
LAWRENCE
COLUMBIA
MONTOUR
UNION
CARBON
MARION
NORTHAMPTON
BEAVER
SNYDER
NORTHUMBERLAND
SCHUYLKILL
LEHIGH
MIFFLIN
JUNIATA
BLAIR
DAUPHIN
BERKS
PERRY
LEBANON
BUCKS
HUNTINGDON
WASHINGTON
MONTGOMERY
CUMBERLAND
LANCASTER
DELMONT
BEDFORD
CHESTER
PHILADELPHIA
GREENE
FAYETTE
FULTON
FRANKLIN
YORK
DELAWARE
ADAMS

PENNSYLVANIA
UPPER FREEPORT (NO 7) SEAM
FIGURE A-10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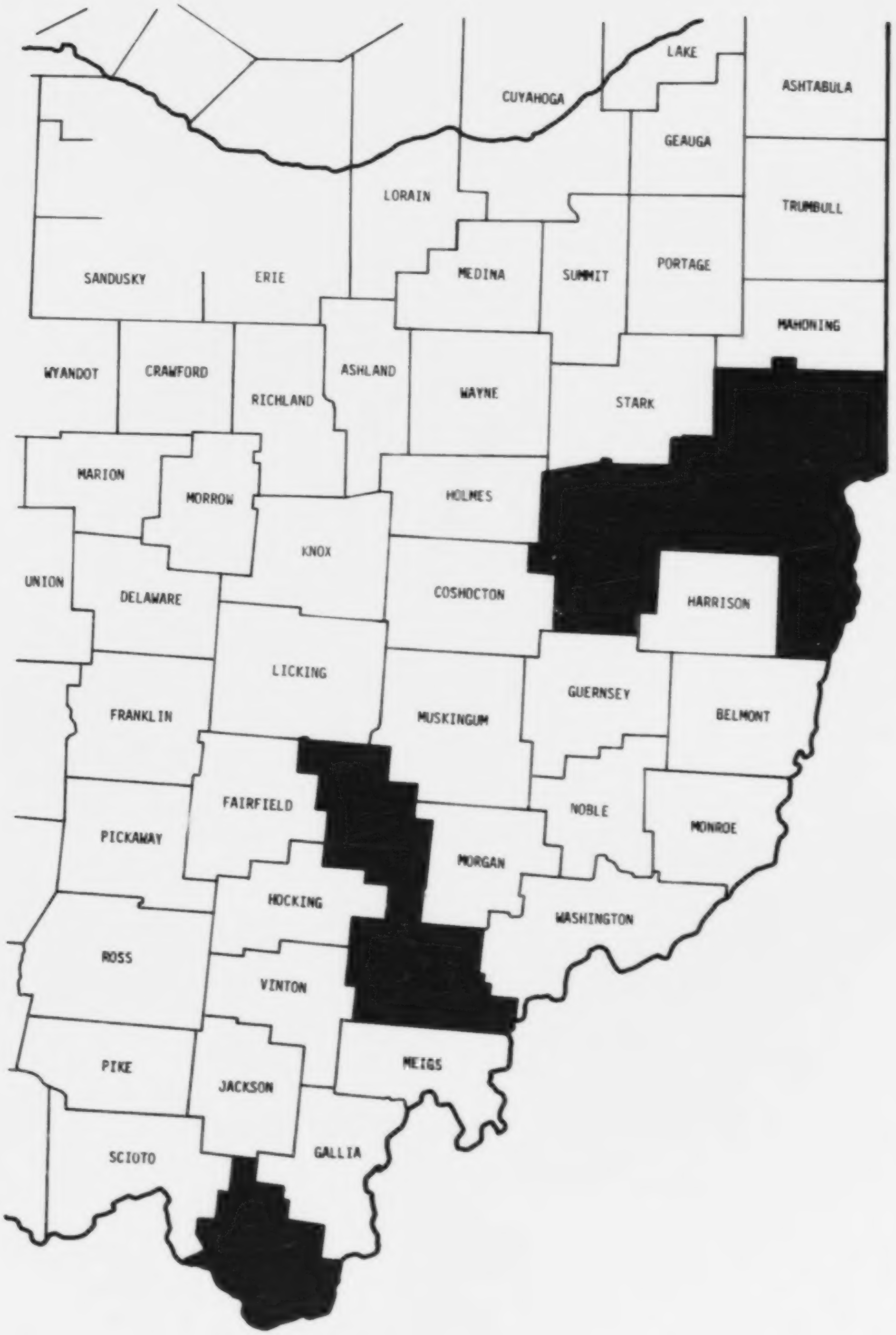
TYLER
PLEASANTS
DODDRIDGE
HARRISON
RITCHIE
GILMER
CALHOUN
WOOD
WIRT
ROANE
JACKSON
MASON
PUTNAM
CABELL
KANAWHA
BOONE
LOGAN
MINGO
WYOMING
MC DOWELL
RALEIGH
FAYETTE
NICHOLAS
MERCER
SUMMERS
MONROE
GREENBRIER
POCAHONTAS
PENDLETON
HARDY
HAMPSHIRE
MORGAN
BERKELEY
JEFFERSON

WEST VIRGINIA
UPPER FREEPORT (NO 7) SEAM

FIGURE A-11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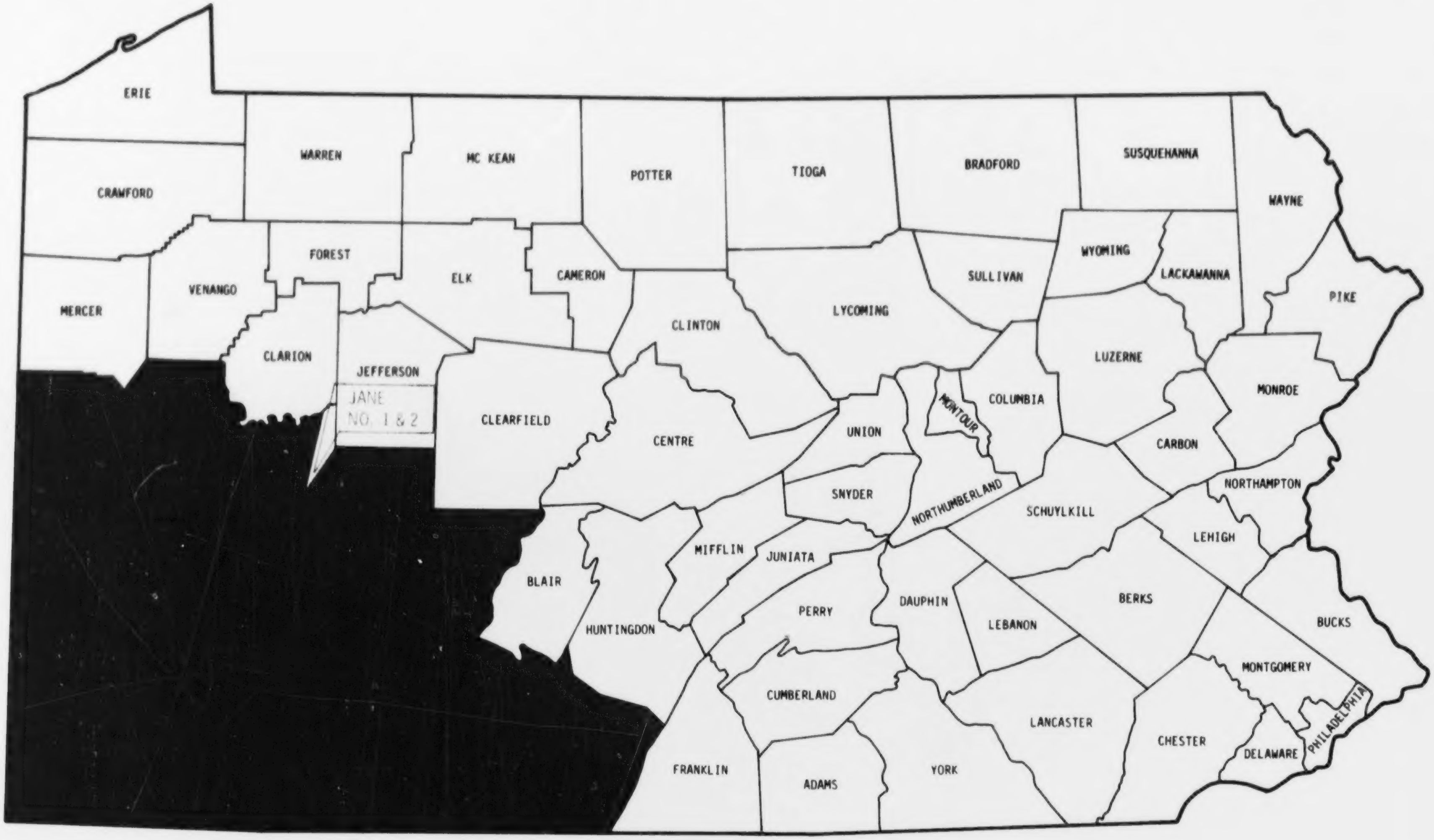
GEAUGA
LORAIN
TRUMBULL
PORTAGE
SANDUSKY
ERIE
MEDINA
SUMMIT
MAHONING
WYANDOT
CRAWFORD
ASHLAND
RICHLAND
WAYNE
STARK
MARION
MORROW
HOLMES
KNOX
UNION
DELAWARE
COSHOCTON
HARRISON
LICKING
GUERNSEY
FRANKLIN
MUSKINGUM
BELMONT
FAIRFIELD
NOBLE
PICKAWAY
MONROE
MORGAN
HOCKING
WASHINGTON
ROSS
VINTON
PIKE
MEIGS
JACKSON
SCIOTO
GALLIA

OHIO

UPPER FREEPORT (NO 7) SEAM

FIGURE A-12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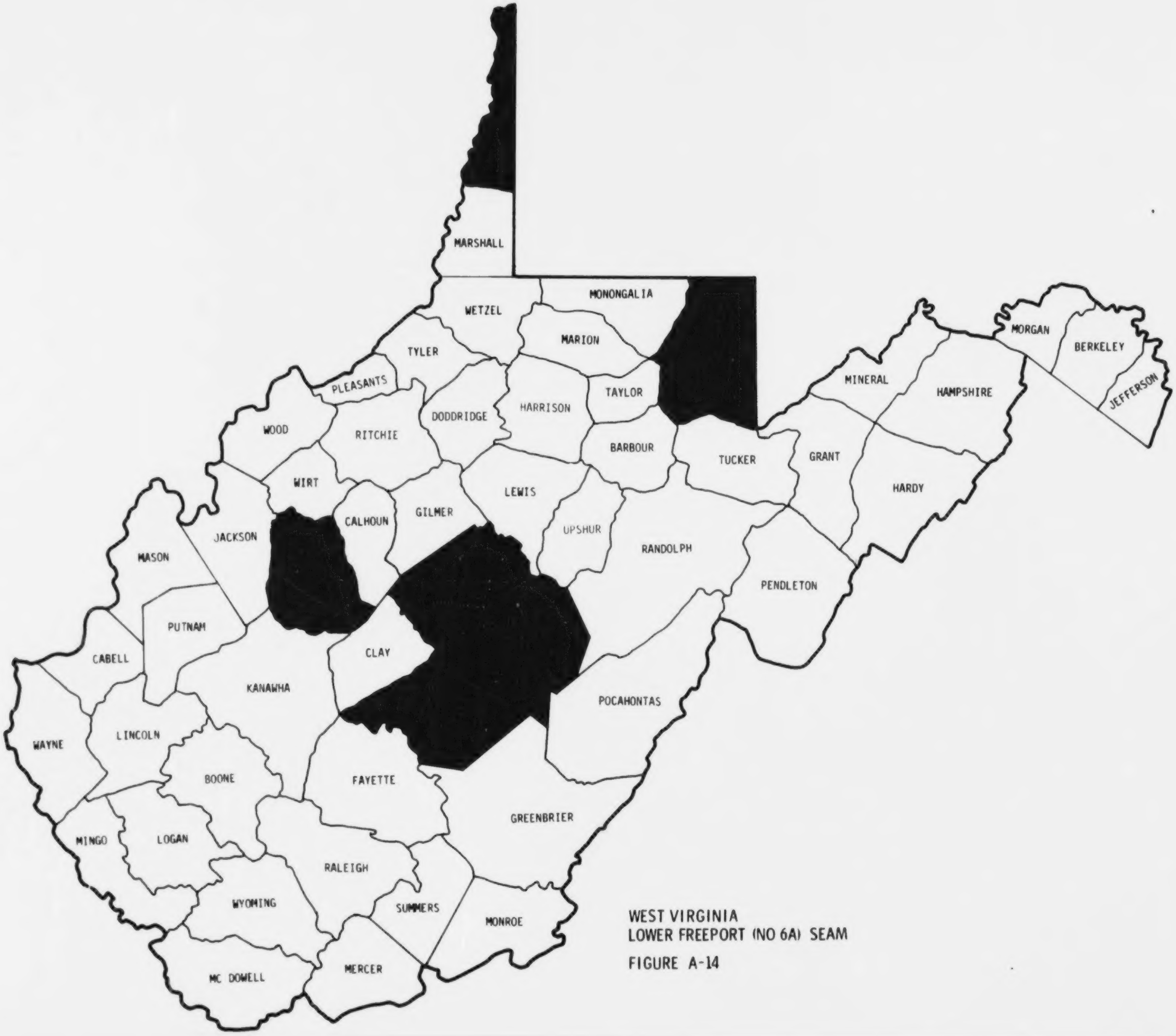
MC KEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
CRAWFORD
FOREST
ELK
CAMERON
WYOMING
LACKAWANNA
PIKE
MERCER
VENANGO
CLARION
JEFFERSON
JANE
NO. 1 & 2
CLEARFIELD
CLINTON
LYCOMING
SULLIVAN
LUZERNE
MONROE
CENTRE
UNION
MONTOUR
COLUMBIA
CARBON
SNYDER
NORTHUMBERLAND
SCHUYLKILL
NORTHAMPTON
LEHIGH
BLAIR
HUNTINGDON
MIFFLIN
JUNIATA
PERRY
DAUPHIN
LEBANON
BERKS
BUCKS
MONTGOMERY
CUMBERLAND
LANCASTER
CHESTER
DELAWARE
PHILADELPHIA
FRANKLIN
ADAMS
YORK

PENNSYLVANIA
LOWER FREEPORT (NO 6A) SEAM
FIGURE A-13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MARION
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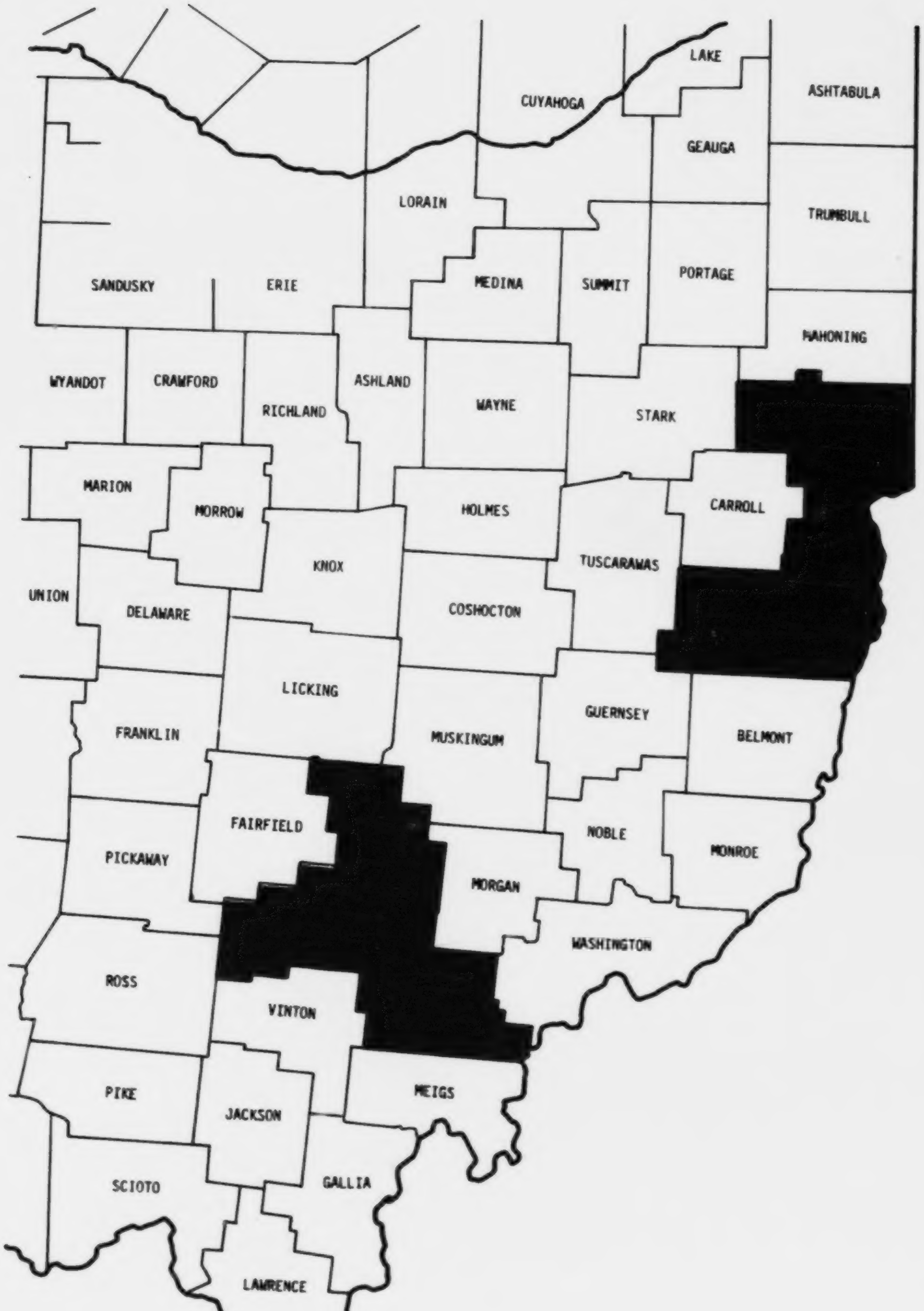
PLEASANTS
TAYLOR
HARRISON
DODDRIDGE
RITCHIE
WOOD
BARBOUR
TUCKER
MINERAL
HAMPSHIRE
MORGAN
BERKELEY
JEFFERSON
GRANT
HARDY
WIRT
CALHOUN
GILMER
LEWIS
UPSHUR
RANDOLPH
PENDLETON
JACKSON
MASON
PUTNAM
CABELL
CLAY
KANAWHA
POCAHONTAS
WAYNE
LINCOLN
BOONE
FAYETTE
GREENBRIER
MINGO
LOGAN
RALEIGH
WYOMING
SUMMERS
MONROE
MC DOWELL
MERCER

WEST VIRGINIA
LOWER FREEPORT (NO 6A) SEAM

FIGURE A-14


LAKE
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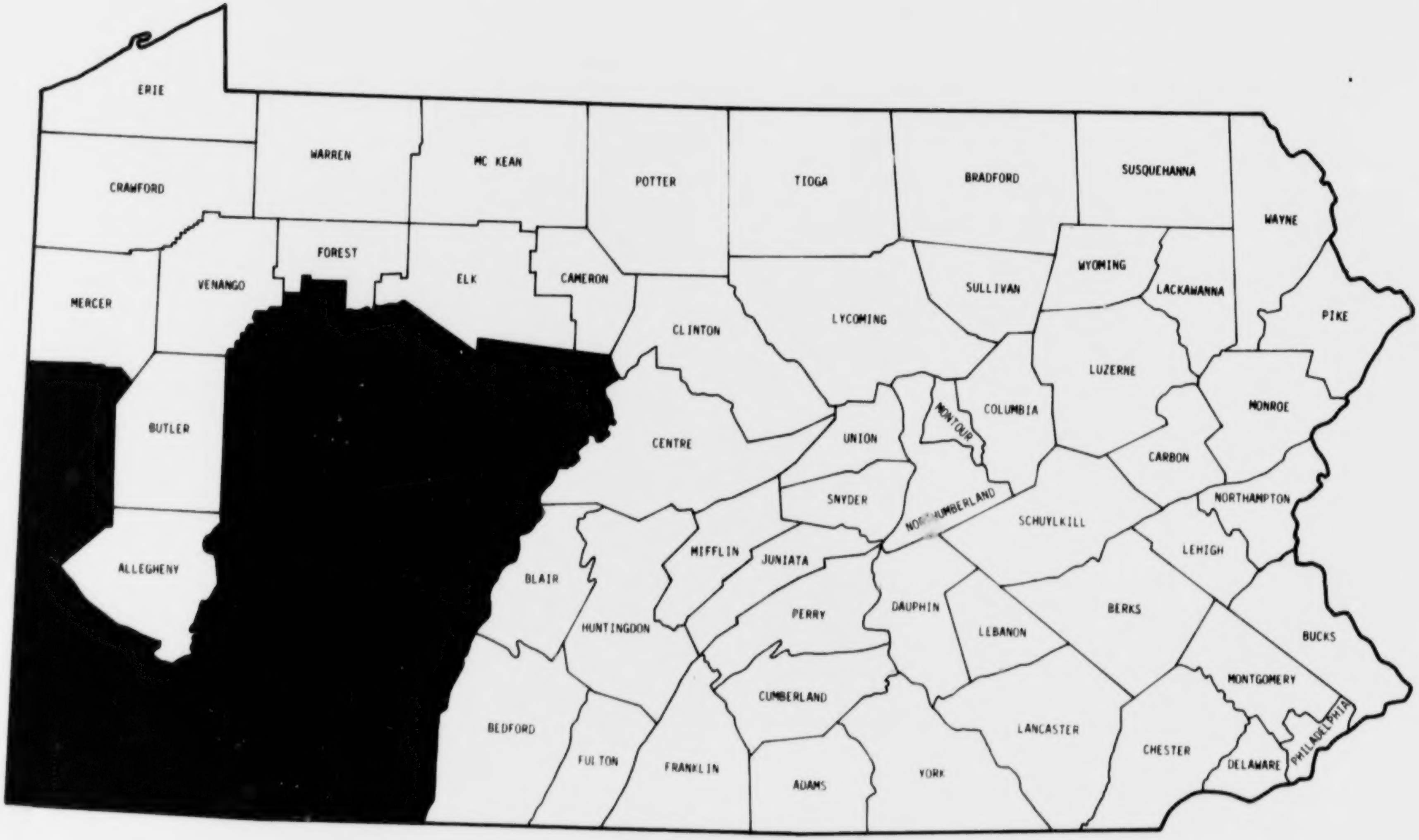
CUYAHOGA
GEAUGA
LORAIN
TRUMBULL
SANDUSKY
ERIE
MEDINA
SUMMIT
PORTAGE
MAHONING
WYANDOT
CRAWFORD
ASHLAND
RICHLAND
WAYNE
STARK
MARION
MORROW
HOLMES
CARROLL
KNOX
TUSCARAWAS
UNION
DELAWARE
COSHOCTON
LICKING
GUERNSEY
FRANKLIN
MUSKINGUM
BELMONT
FAIRFIELD
NOBLE
PICKAWAY
MONROE
MORGAN
WASHINGTON
ROSS
VINTON
PIKE
MEIGS
JACKSON
SCIOTO
GALLIA
LAWRENCE

OHIO
LOWER FREEPORT (NO 6A) SEAM
FIGURE A-15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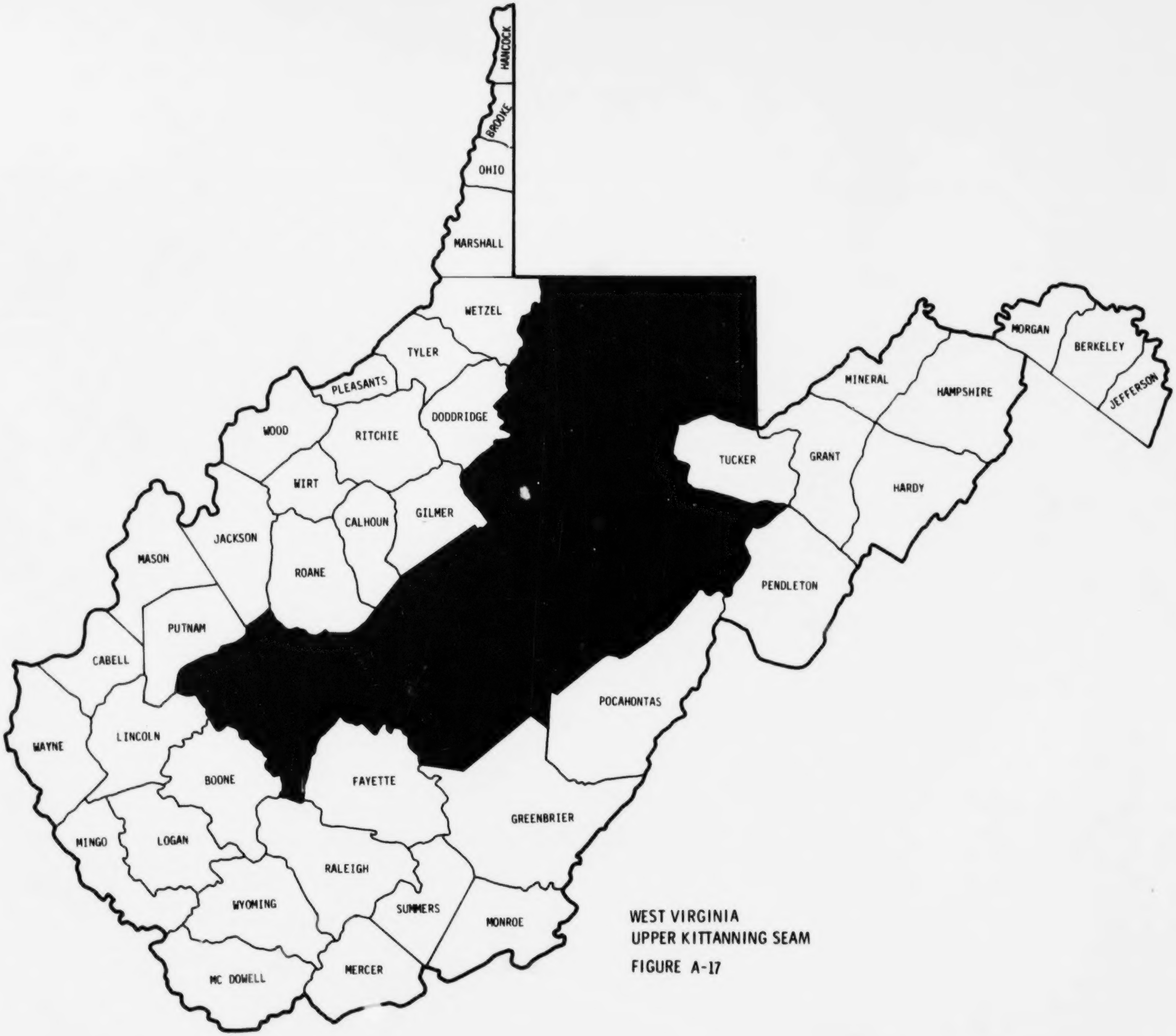
WARREN
MC KEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
CRAWFORD
FOREST
ELK
CAMERON
MERCER
VENANGO
LYCOMING
SULLIVAN
WYOMING
LACKAWANNA
PIKE
CLINTON
LUZERNE
BUTLER
CENTRE
UNION
MONTOUR
COLUMBIA
MONROE
CARBON
SNYDER
NORTHUMBERLAND
NORTHAMPTON
SCHUYLKILL
ALLEGHENY
BLAIR
MIFFLIN
JUNIATA
LEHIGH
HUNTINGDON
PERRY
DAUPHIN
BERKS
LEBANON
BUCKS
MONTGOMERY
CUMBERLAND
BEDFORD
LANCASTER
PHILADELPHIA
FULTON
FRANKLIN
CHESTER
DELAWARE
ADAMS
YORK

PENNSYLVANIA
UPPER KITTANNING SEAM

FIGURE A-16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BROOKE
OHIO
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PLEASANTS
DODDRIDGE
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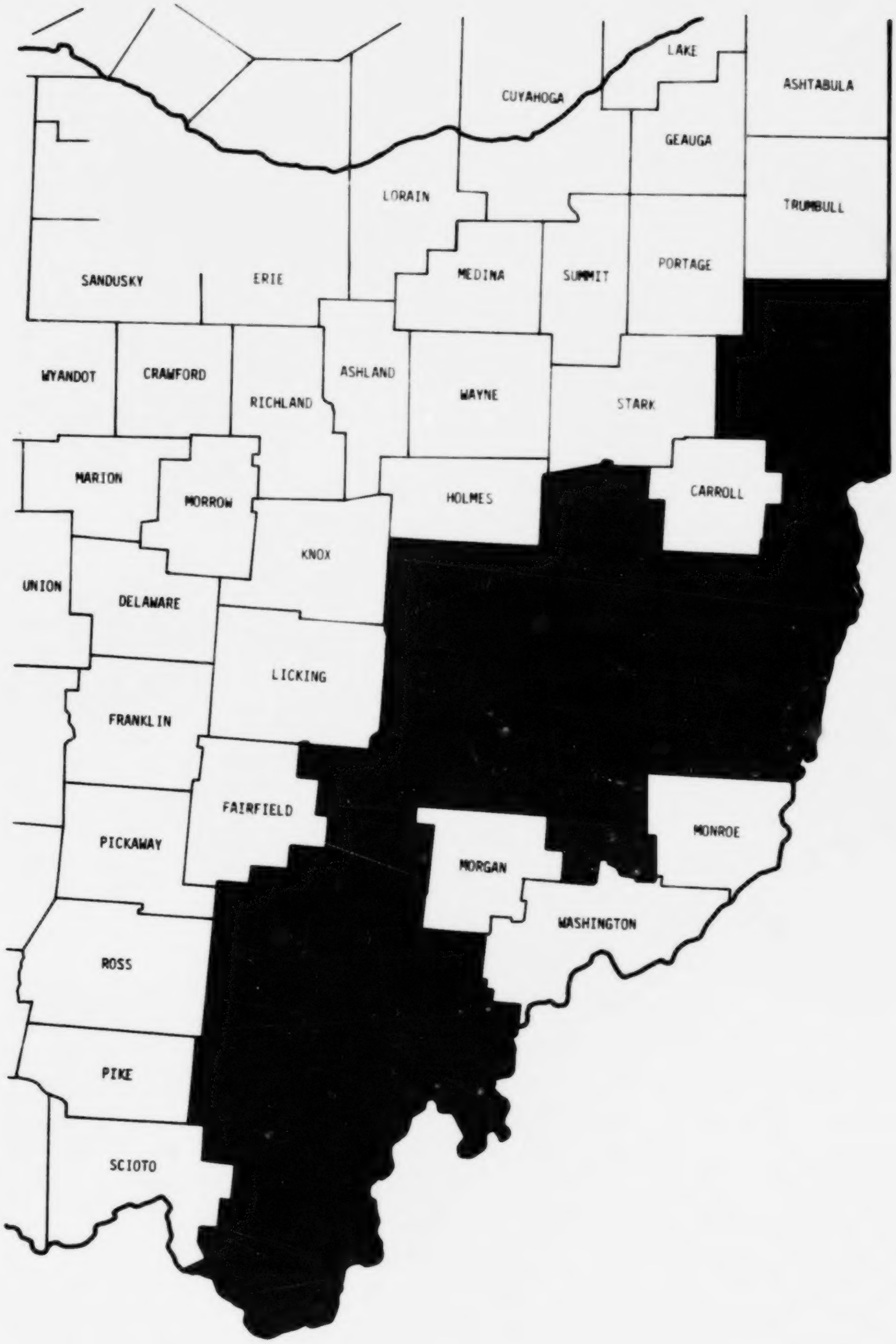
RITCHIE
WIRT
CALHOUN
GILMER
JACKSON
ROANE
MASON
PUTNAM
CABELL
WAYNE
LINCOLN
BOONE
FAYETTE
MINGO
LOGAN
RALEIGH
WYOMING
SUMMERS
MC DOWELL
MERCER
MONROE
GREENBRIER
POCAHONTAS
PENDLETON
TUCKER
GRANT
HARDY
MINERAL
HAMPSHIRE
MORGAN
BERKELEY
JEFFERSON

WEST VIRGINIA
UPPER KITTANNING SEAM
FIGURE A-17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TRUMBULL
MEDINA
SUMMIT
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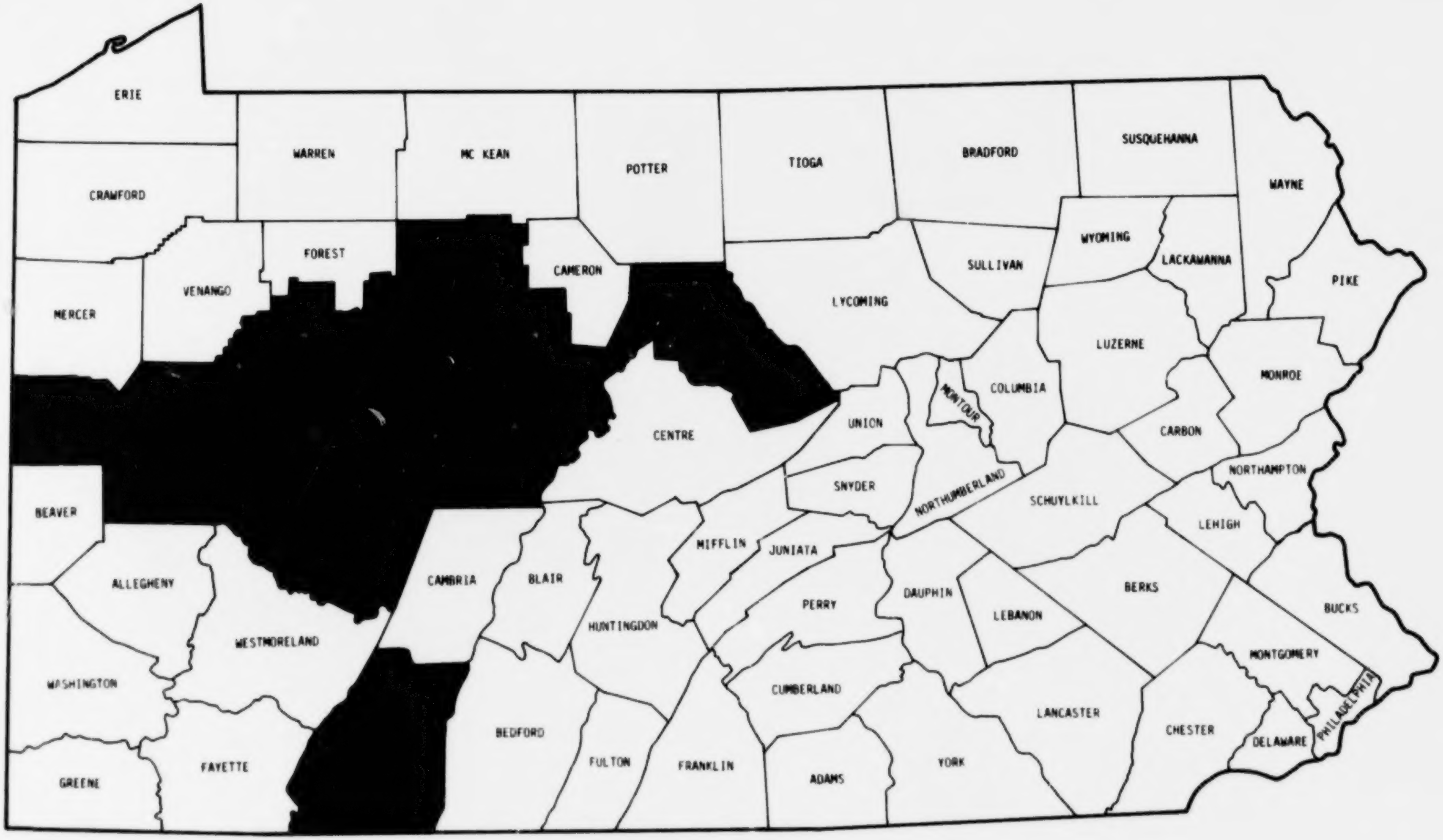
SANDUSKY
ERIE
WYANDOT
CRAWFORD
RICHLAND
ASHLAND
WAYNE
STARK
MARION
MORROW
HOLMES
CARROLL
KNOX
UNION
DELAWARE
LICKING
FRANKLIN
FAIRFIELD
MONROE
PICKAWAY
MORGAN
WASHINGTON
ROSS
PIKE
SCIOTO

OHIO
UPPER KITTANNING SEAM

FIGURE A-18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WARREN
MC KEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
CRAWFORD
FOREST
CAMERON
LYCOMING
SULLIVAN
WYOMING
LACKAWANNA
PIKE
MERCER
VENANGO
LUZERNE
MONROE
COLUMBIA
MONTOUR
UNION
CENTRE
CARBON
NORTHAMPTON
BEAVER
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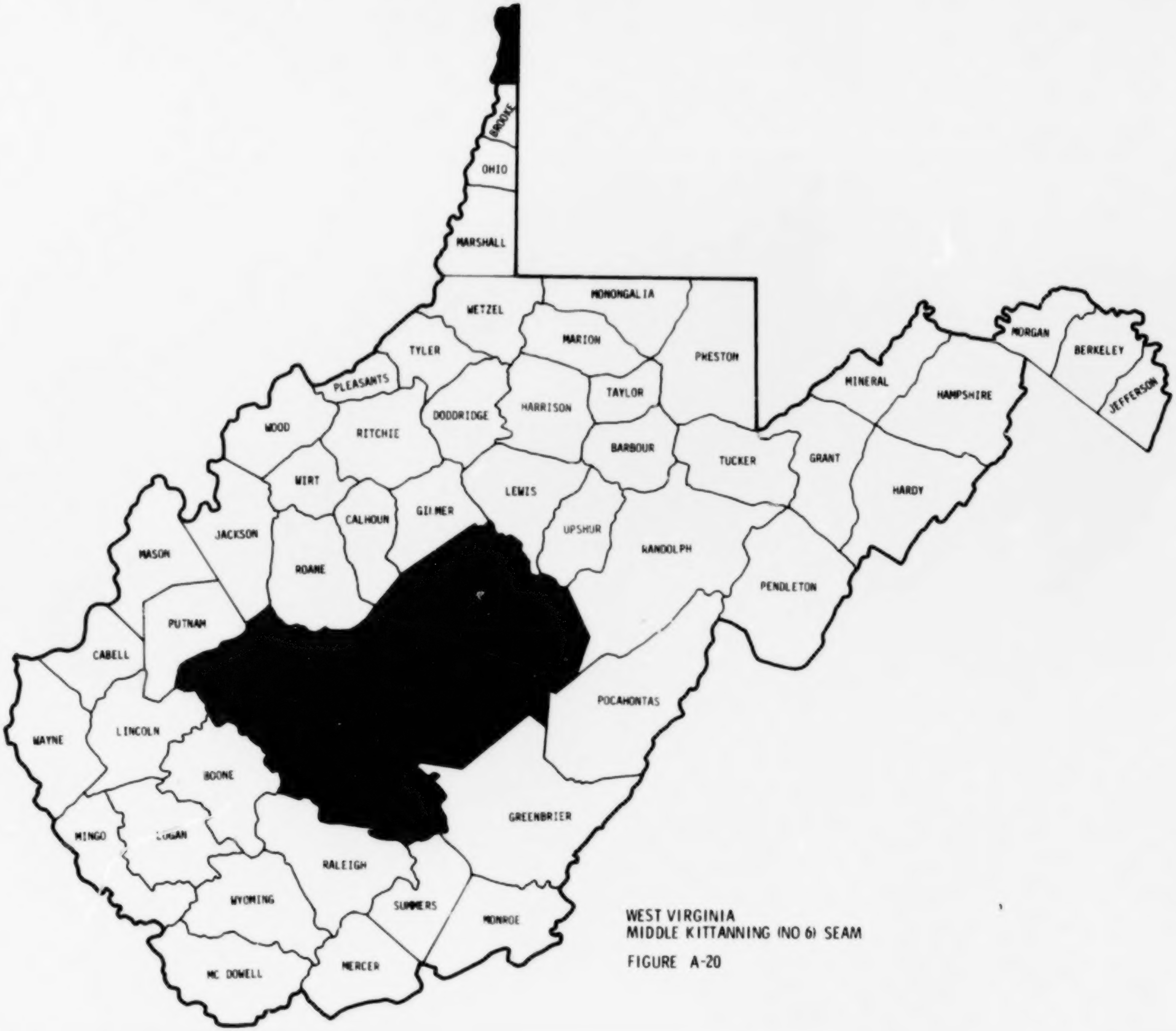
NORTHUMBERLAND
SCHUYLKILL
LEHIGH
MIFFLIN
JUNIATA
ALLEGHENY
CAMBRIA
BLAIR
PERRY
DAUPHIN
BERKS
BUCKS
HUNTINGDON
LEBANON
WESTMORELAND
MONTGOMERY
WASHINGTON
CUMBERLAND
PHILADELPHIA
LANCASTER
BEDFORD
CHESTER
DELAWARE
FULTON
FRANKLIN
YORK
ADAMS
GREENE
FAYETTE

PENNSYLVANIA
MIDDLE KITTANNING (NO 6) SEAM
FIGURE A-19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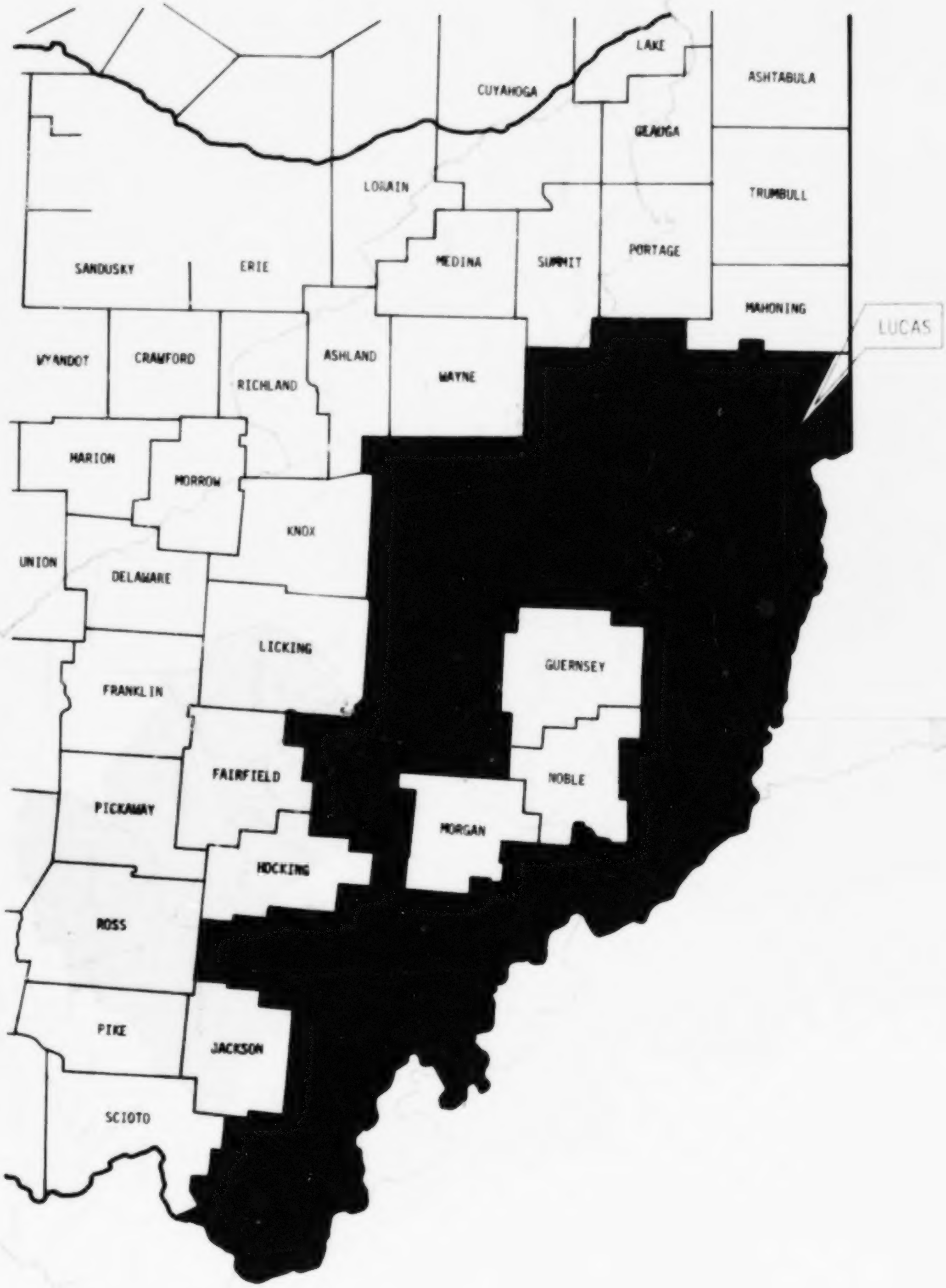
OHIO
MARSHALL
WETZEL
MONONGALIA
MARION
PRESTON
TYLER
PLEASANTS
WOOD
RITCHIE
DODDRIDGE
HARRISON
TAYLOR
BARBOUR
TUCKER
MORGAN
BERKELEY
JEFFERSON
MINERAL
HAMPSHIRE
GRANT
HARDY
WIRT
CALHOUN
GILMER
LEWIS
UPSHUR
RANDOLPH
PENDLETON
JACKSON
MASON
ROANE
PUTNAM
CABELL
POCAHONTAS
WAYNE
LINCOLN
BOONE
GREENBRIER
MINGO
LOGAN
RALEIGH
WYOMING
SUMMERS
MONROE
MC DOWELL
MERCER

WEST VIRGINIA
MIDDLE KITTANNING (NO 6) SEAM

FIGURE A-20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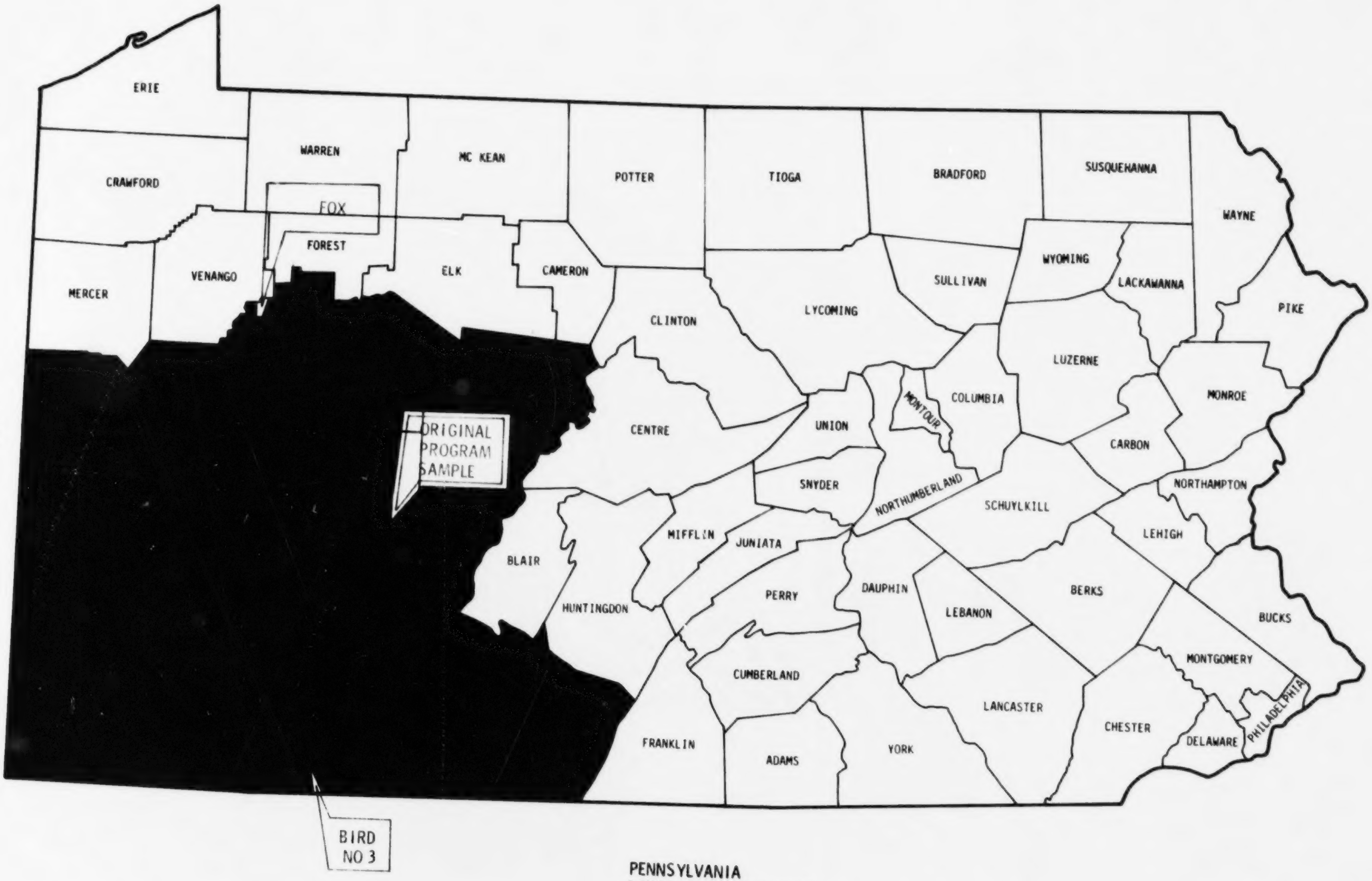
CUYAHOGA
ASHTABULA
GEAUGA
LORAIN
TRUMBULL
MEDINA
SUMMIT
PORTAGE
SANDUSKY
ERIE
MAHONING
LUCAS
WYANDOT
CRAWFORD
ASHLAND
RICHLAND
WAYNE
MARION
MORROW
KNOX
UNION
DELAWARE
LICKING
GUERNSEY
FRANKLIN
FAIRFIELD
NOBLE
PICKAWAY
MORGAN
HOCKING
ROSS
PIKE
JACKSON
SCIOTO

OHIO

MIDDLE KITTANNING (NO6) SEAM

FIGURE A-21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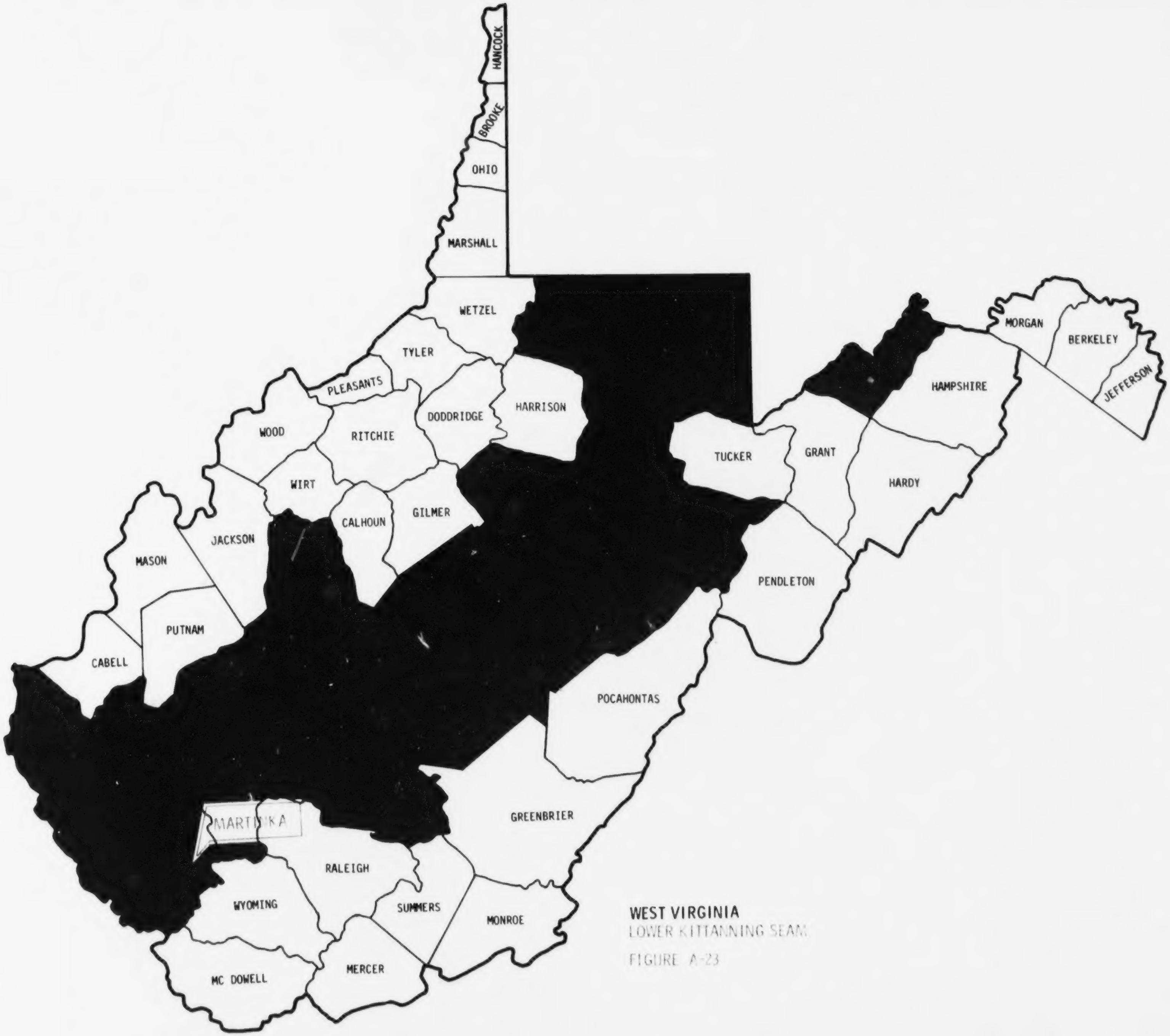
WARREN
MC KEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
CRAWFORD
FOX
FOREST
MERCER
VENANGO
ELK
CAMERON
CLINTON
LYCOMING
SULLIVAN
WYOMING
LACKAWANNA
PIKE
LUZERNE
MONROE
CENTRE
UNION
MONTOUR
COLUMBIA
CARBON
ORIGINAL PROGRAM SAMPLE
SNYDER
NORTHUMBERLAND
SCHUYLKILL
NORTHAMPTON
MIFFLIN
JUNIATA
LEHIGH
BLAIR
HUNTINGDON
PERRY
DAUPHIN
LEBANON
BERKS
BUCKS
CUMBERLAND
MONTGOMERY
LANCASTER
CHESTER
FRANKLIN
ADAMS
YORK
DELAWARE
PHILADELPHIA
BIRD NO 3

PENNSYLVANIA
LOWER KITTANNING SEAM

FIGURE A-22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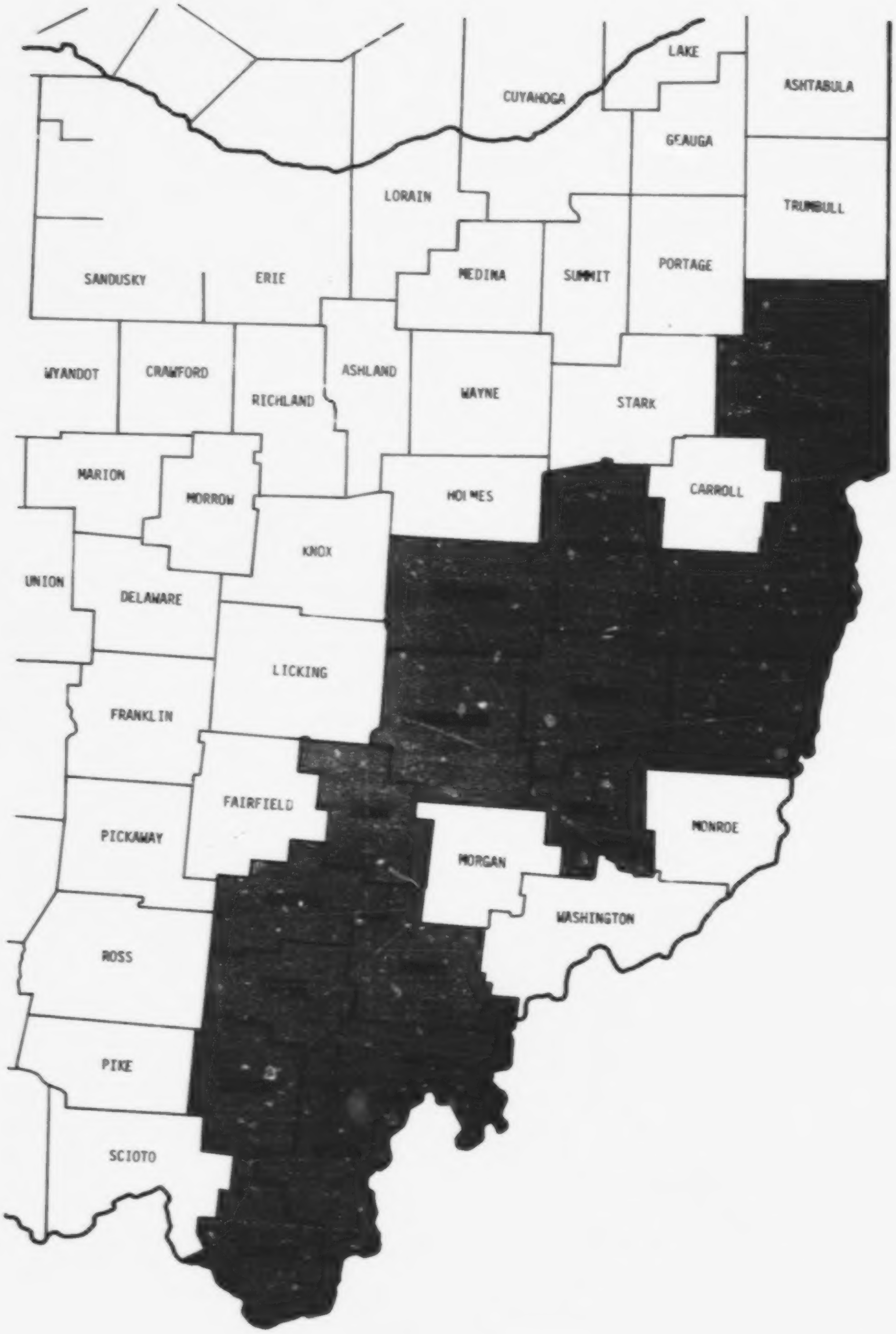
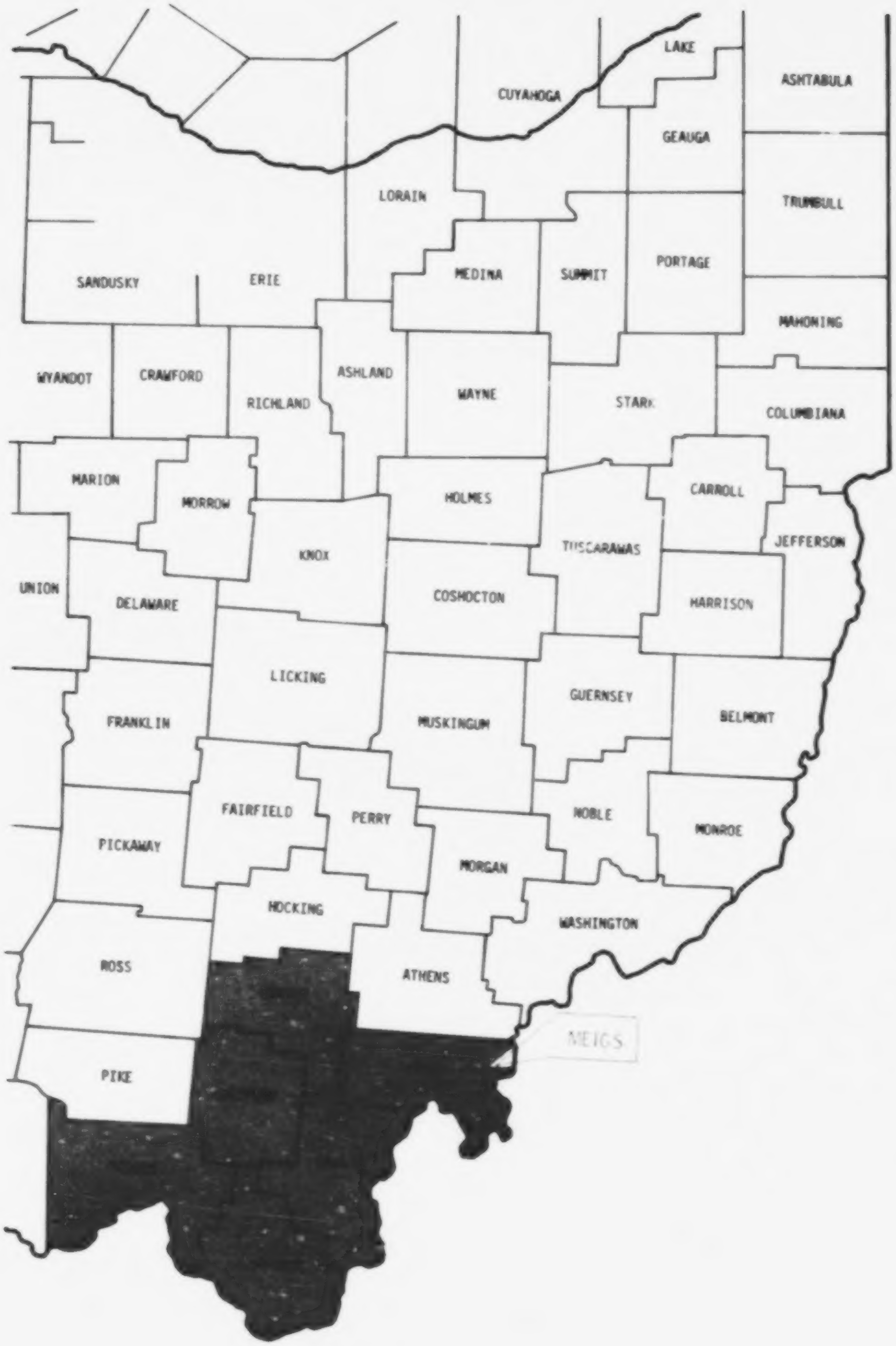
BROOKE
OHIO
MARSHALL
WETZEL
TYLER
PLEASANTS
HARRISON
DODDRIDGE
RITCHIE
WOOD
WIRT
CALHOUN
GILMER
JACKSON
MASON
PUTNAM
CABELL
TUCKER
GRANT
HAMPSHIRE
MORGAN
BERKELEY
JEFFERSON
HARDY
PENDLETON
POCAHONTAS
GREENBRIER
MARTINKA
RALEIGH
WYOMING
SUMMERS
MONROE
MC DOWELL
MERCER

WEST VIRGINIA
LOWER KITTANNING SEAM
FIGURE A-23


LAKE
ASHTABULA
CUYAHOGA
GEAUGA
TRUMBULL
LORAIN
SANDUSKY
ERIE
MEDINA
SUMMIT
PORTAGE
WYANDOT
CRAWFORD
RICHLAND
ASHLAND
WAYNE
STARK
MARION
MORROW
HOLMES
CARROLL
KNOX
UNION
DELAWARE
LICKING
FRANKLIN
FAIRFIELD
PICKAWAY
MONROE
MORGAN
WASHINGTON
ROSS
PIKE
SCIOTO

OHIO
LOWER KITTANNING SEAM
FIGURE A-24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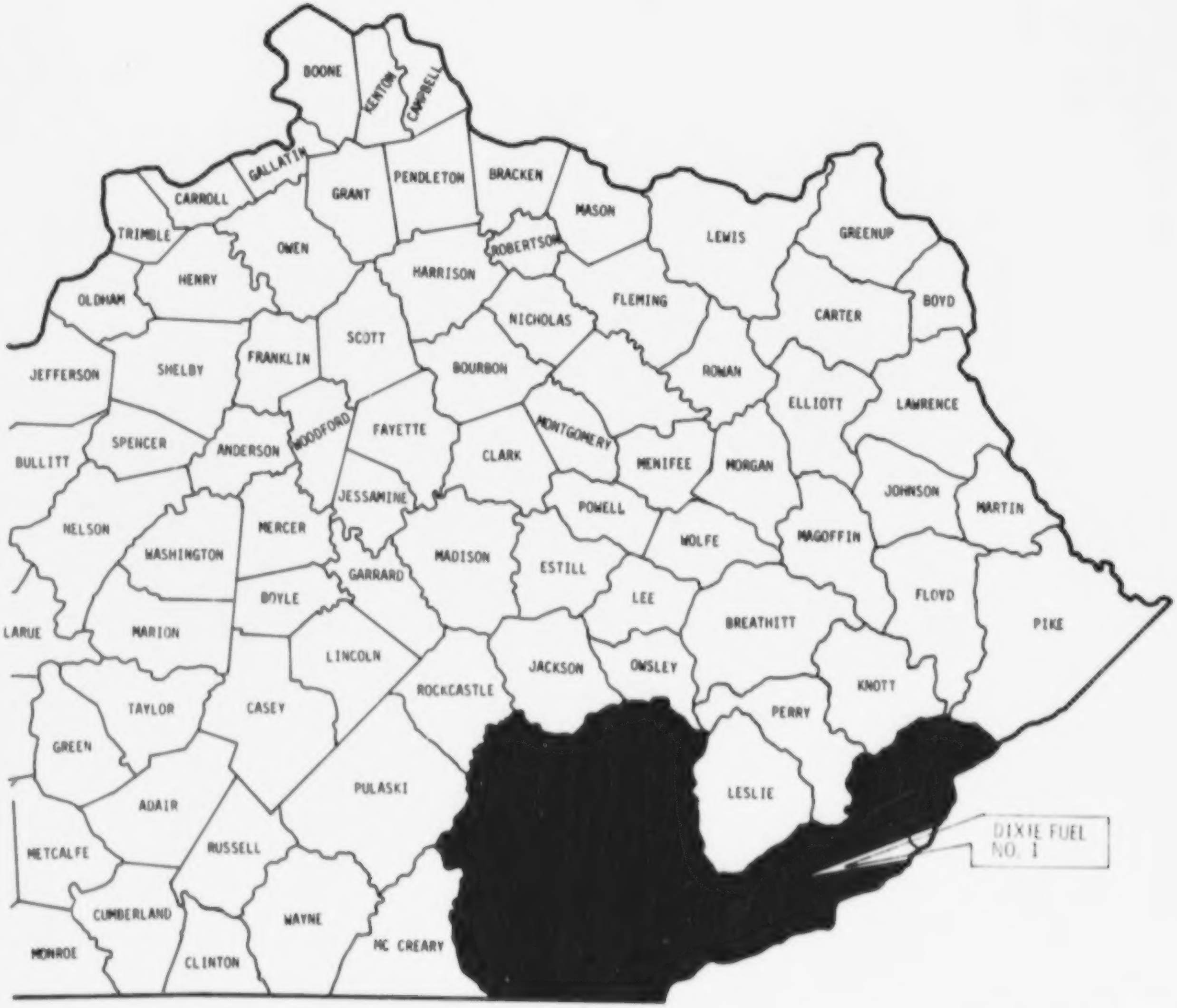
CUYAHOGA
GEAUGA
TRUMBULL
LORAIN
MEDINA
SUMMIT
PORTAGE
SANDUSKY
ERIE
MAHONING
WYANDOT
CRAWFORD
RICHLAND
ASHLAND
WAYNE
STARK
COLUMBIANA
MARION
MORROW
HOLMES
CARROLL
KNOX
TUSCARAWAS
JEFFERSON
UNION
DELAWARE
COSHOCTON
HARRISON
LICKING
GUERNSEY
FRANKLIN
MUSKINGUM
BELMONT
FAIRFIELD
PERRY
NOBLE
MONROE
PICKAWAY
MORGAN
HOCKING
WASHINGTON
ROSS
ATHENS
MEIGS
PIKE

OHIO
CLARION 4A SEAM

FIGURE A-25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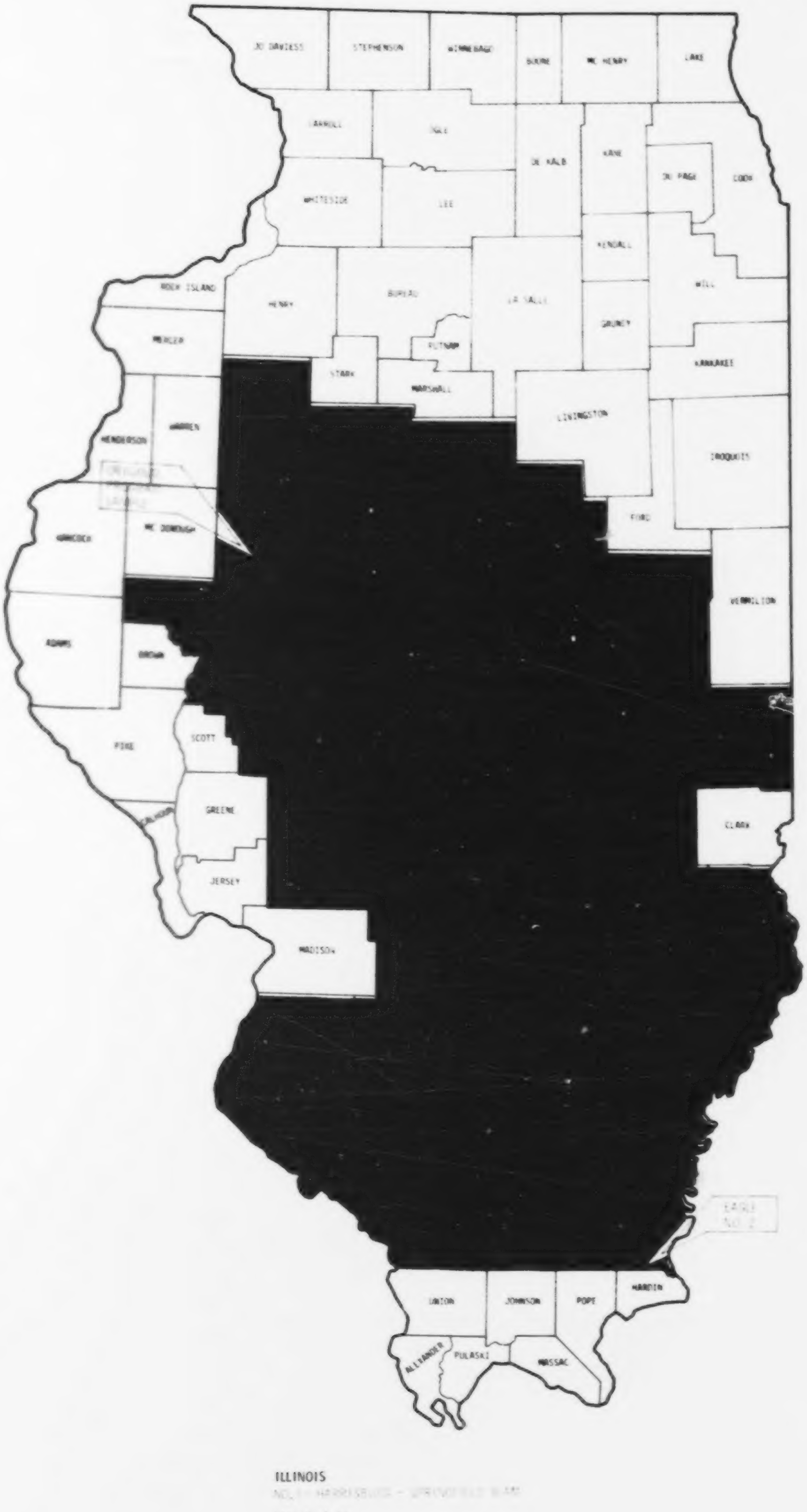
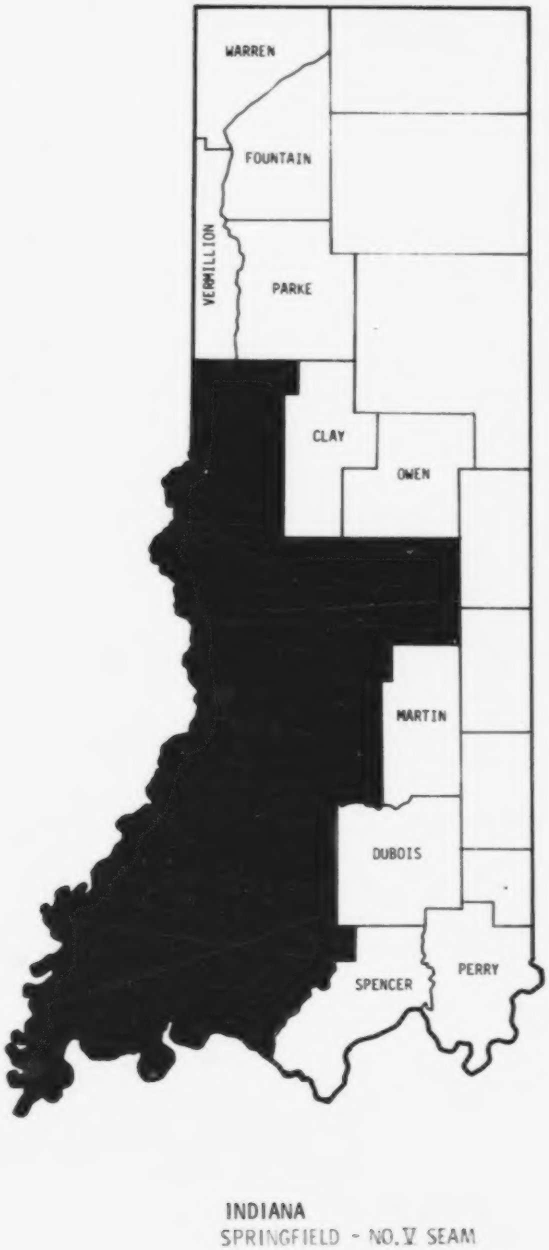
CAMPBELL
GALLATIN
CARROLL
TRIMBLE
GRANT
PENDLETON
BRACKEN
MASON
LEWIS
GREENUP
OLDHAM
HENRY
OWEN
HARRISON
ROBERTSON
NICHOLAS
FLEMING
CARTER
BOYD
JEFFERSON
SHELBY
FRANKLIN
SCOTT
BOURBON
ROWAN
ELLIOTT
LAWRENCE
BULLITT
SPENCER
ANDERSON
WOODFORD
FAYETTE
CLARK
MONTGOMERY
MENIFEE
MORGAN
JOHNSON
MARTIN
NELSON
WASHINGTON
MERCER
JESSAMINE
POWELL
WOLFE
MAGOFFIN
MADISON
ESTILL
LEE
BREATHITT
FLOYD
PIKE
GARRARD
BOYLE
LARUE
MARION
LINCOLN
JACKSON
OWSLEY
KNOTT
ROCKCASTLE
PERRY
TAYLOR
CASEY
GREEN
PULASKI
LESLIE
ADAIR
DIXIE FUEL
NO. 1
METCALFE
RUSSELL
CUMBERLAND
WAYNE
MC CREARY
MONROE
CLINTON

EASTERN KENTUCKY
MASON SEAM

FIGURE A-26

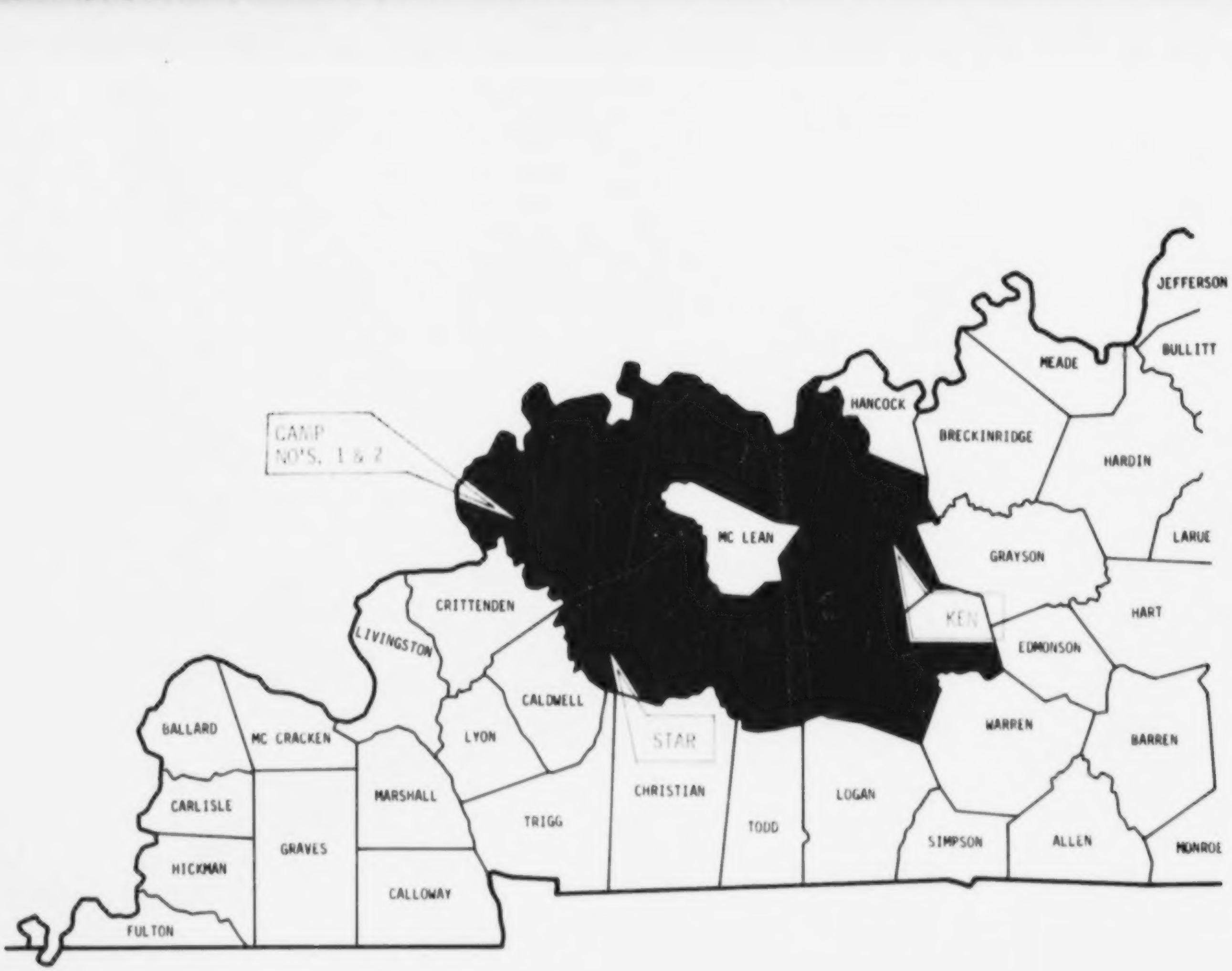

JO DAVIESS
STEPHENSON
WINNEBAGO
BOONE
MC HENRY
LAKE
CARROLL
OGLE
DE KALB
KANE
DU PAGE
COOK
WHITESIDE
LEE
KENDALL
ROCK ISLAND
HENRY
BUREAU
LA SALLE
WILL
GRUNDY
MERCER
PUTNAM
KANKAKEE
STARK
MARSHALL
LIVINGSTON
HENDERSON
WARREN
IROQUOIS
HANCOCK
MC DONOUGH
FORD
VERMILION
ADAMS
BROWN
SCOTT
PIKE
CALHOUN
GREENE
CLARK
JERSEY
MADISON
EAGLE
NO. 2
UNION
JOHNSON
POPE
HARDIN
ALEXANDER
PULASKI
MASSAC

ILLINOIS
NO. 5 – HARRISBURG – SPRINGFIELD SEAM
FIGURE A-27

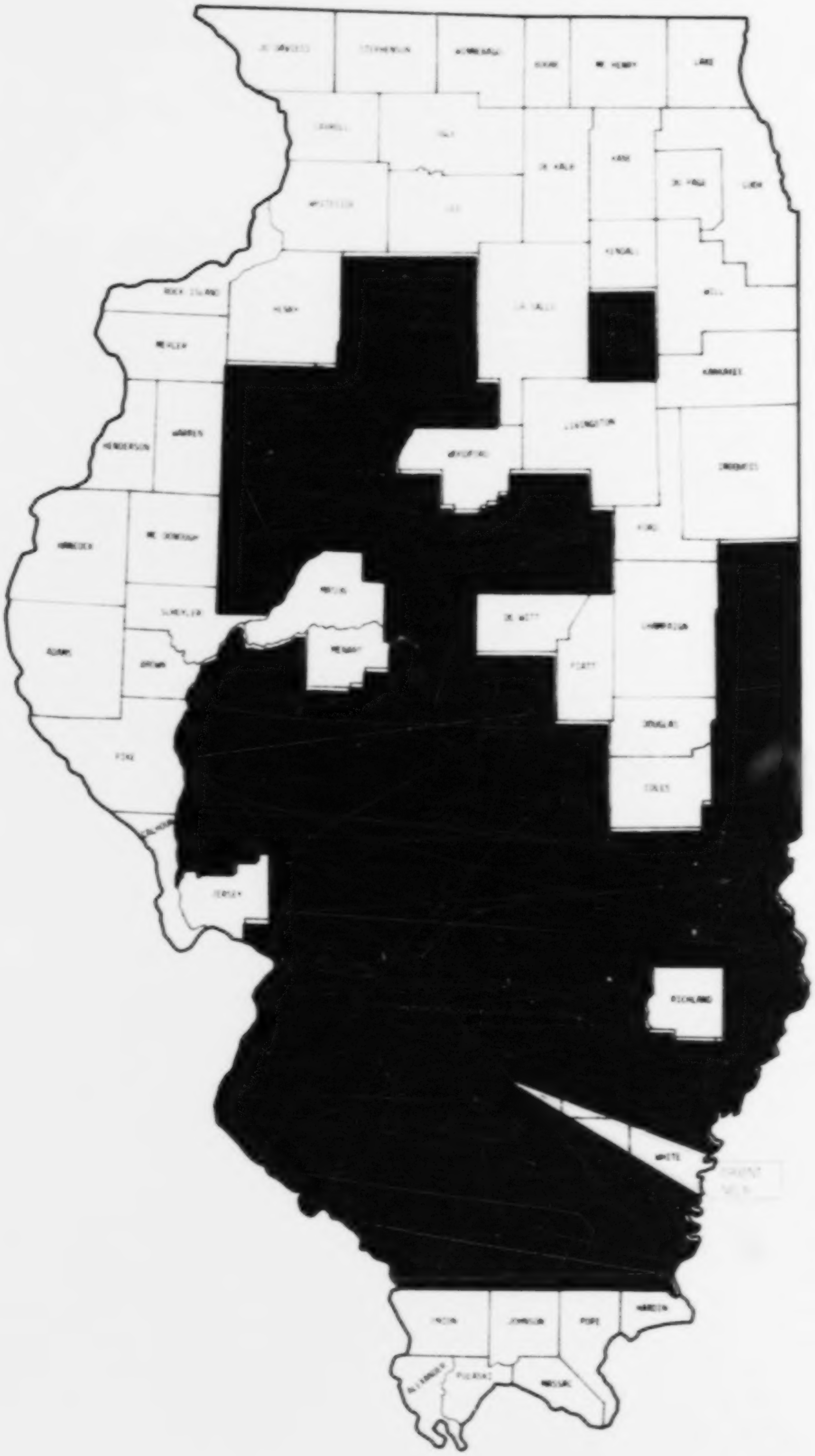

WARREN
FOUNTAIN
VERMILLION
PARKE
CLAY
OWEN
MARTIN
DUBOIS
SPENCER
PERRY

INDIANA
SPRINGFIELD - NO.V SEAM

FIGURE A-28


CAMP
NO'S. 1 & 2
KEN
STAR
JEFFERSON
BULLITT
MEADE
HANCOCK
BRECKINRIDGE
HARDIN
LARUE
MC LEAN
GRAYSON
HART
CRITTENDEN
LIVINGSTON
EDMONSON
CALDWELL
BALLARD
MC CRACKEN
LYON
WARREN
BARREN
MARSHALL
CHRISTIAN
LOGAN
CARLISLE
TRIGG
TODD
SIMPSON
ALLEN
MONROE
GRAVES
HICKMAN
CALLOWAY
FULTON

WESTERN KENTUCKY
NO. 9 SEAM
FIGURE A-29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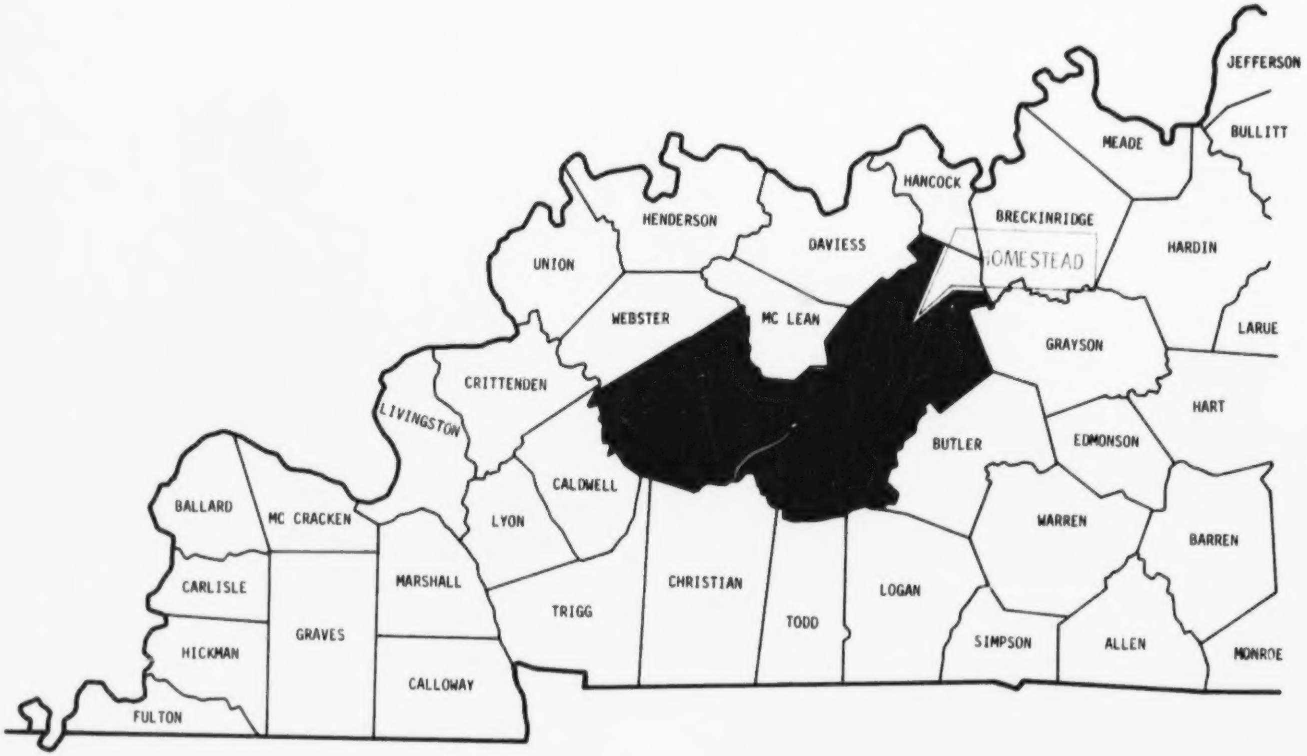
WINNEBAGO
BOONE
MC HENRY
LAKE
CARROLL
OGLE
DE KALB
KANE
DU PAGE
COOK
WHITESIDE
LEE
KENDALL
ROCK ISLAND
HENRY
LA SALLE
WILL
MERCER
KANKAKEE
HENDERSON
WARREN
LIVINGSTON
WOODFORD
IROQUOIS
HANCOCK
MC DONOUGH
FORD
MASON
SCHUYLER
DE WITT
CHAMPAIGN
ADAMS
BROWN
MENARD
PIATT
DOUGLAS
PIKE
COLES
CALHOUN
JERSEY
RICHLAND
WHITE
UNION
JOHNSON
POPE
HARDIN
ALEXANDER
PULASKI
MASSAC

ILLINOIS
[illegible]
FIGURE A-36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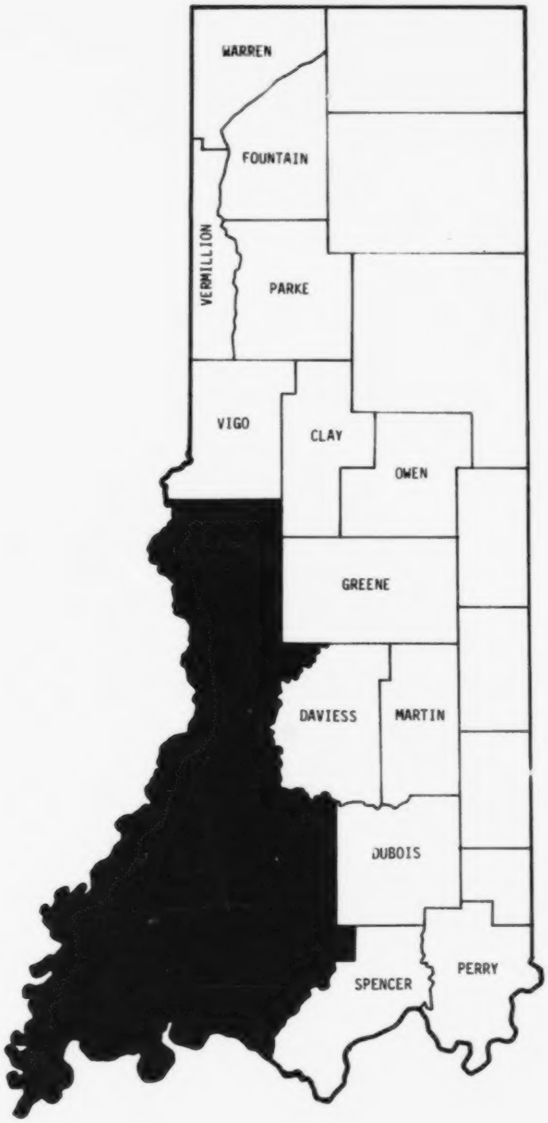
BULLITT
MEADE
HANCOCK
BRECKINRIDGE
HARDIN
HENDERSON
DAVIESS
HOMESTEAD
UNION
WEBSTER
MC LEAN
LARUE
GRAYSON
CRITTENDEN
HART
LIVINGSTON
BUTLER
EDMONSON
CALDWELL
BALLARD
MC CRACKEN
LYON
WARREN
BARREN
MARSHALL
CARLISLE
CHRISTIAN
LOGAN
TRIGG
GRAVES
TODD
HICKMAN
SIMPSON
ALLEN
MONROE
CALLOWAY
FULTON

WESTERN KENTUCKY
NO. 11 SEAM
FIGURE A-31


WARREN
FOUNTAIN
VERMILLION
PARKE
VIGO
CLAY
OWEN
GREENE
DAVIESS
MARTIN
DUBOIS
SPENCER
PERRY

INDIANA
HYMERA - NO.VI SEAM
FIGURE NO. A-32

APPENDIX B

RANKING OF TREATED AND UNTREATED COALS

NOTE: The values used for the calculations in this appendix are the average of the triplicate determinations detailed in Appendices C and D.

The EPA standard % sulfur will yield 1.2 lbs $SO_2/10^6$ btu.

Table B-1

COAL RANKING DATA-UNTREATED COAL
FINAL TWENTY COALS

Mine	Seam	Moisture %	Sulfur %	Ash %	BTU				Fixed Carbon		Volatile Matter		EPA Standard % Sulfur	Class
					Moist	Dry	Moist Mineral Matter Free	Dry Mineral Matter Free	Dry	Dry Mineral Matter Free	Dry	Dry Mineral Matter Free		
Muskinoum	Meigs Creek No. 9	3.36	6.08	21.68	10644	11014	14118	14608	41.96	56.04	36.36	43.96	0.66	II-3
Powhattan No. 4	Pittsburgh No. 8	2.10	4.12	37.17	8422	8603	14267	14573	33.82	57.65	29.01	42.35	0.52	II-3
Isabella	Pittsburgh	1.57	1.57	42.22	8087	8216	14958	15197	33.09	61.37	24.69	38.63	0.49	II-3
Mathies	Pittsburgh	2.15	1.46	41.01	7979	8154	14399	14715	34.46	62.36	24.53	37.64	0.49	II-3
Williams	Pittsburgh	1.28	3.48	13.18	12846	13013	15113	15309	48.18	56.84	38.64	43.16	0.78	II-3
Robinson Run	Pittsburgh	0.96	4.38	13.36	12838	12962	15173	15321	47.76	56.64	38.88	43.36	0.78	II-3
Shoemaker	Pittsburgh	1.51	3.51	33.48	9352	9495	14821	15049	35.39	56.31	31.13	43.69	0.57	II-3
Delmont	Upper Freeport	0.77	4.89	27.18	10927	11012	15720	15842	44.49	64.39	28.33	35.61	0.66	II-3
Marion	Upper Freeport	1.84	1.37	26.40	10843	11046	15232	15517	49.15	69.19	24.45	30.81	0.66	II-2
Lucas	Middle Kittanning	3.88	1.79	8.68	12929	13451	14323	14902	56.02	62.19	35.30	37.81	0.81	II-3
Bird No. 3	Lower Kittanning	0.84	3.14	30.23	10461	10550	15702	15835	53.59	80.94	16.18	19.06	0.63	II-1
Martinka	Lower Kittanning	1.84	1.96	49.64	7413	7552	16144	16447	28.76	62.82	21.60	37.18	0.45	II-3
Meigs	Clarion 4A	4.77	3.73	26.53	9757	10246	13811	14503	38.55	54.82	34.92	45.18	0.61	II-4
Dean	Dean	1.06	4.09	17.28	11979	12107	14887	15047	45.81	57.15	36.91	42.85	0.73	II-3
Kopperston	Campbell Creek	1.38	0.91	30.15	10806	10957	16075	16300	45.96	68.46	23.89	31.54	0.66	II-3
Harris Nos. 1&2	Eagle & No. 2 Gas	1.72	1.00	18.63	12200	12414	15316	15585	54.51	68.52	26.86	31.48	0.74	II-3
North River	Corona	1.57	2.06	49.25	7572	7693	16352	16613	27.56	59.66	23.19	40.34	0.46	II-3
Homestead	No. 11	5.41	4.46	16.56	11289	11935	13892	14686	50.30	62.30	33.14	37.70	0.72	II-4
Ken	No. 9	4.76	4.83	15.08	11523	12099	13918	14614	49.66	60.37	35.26	39.63	0.73	II-4
Star	No. 9	6.13	4.32	13.90	11554	12308	13724	14620	52.16	62.35	33.94	37.65	0.74	II-4

Class: II-1, Bituminous - Low Volatile (lvb)
II-2, Bituminous - Medium Volatile (mvb)
II-3, Bituminous - High Volatile A (hvAb)
II-4, Bituminous - High Volatile B (hvBb)

Table B-2

COAL RANKING DATA - UNTREATED COAL
INITIAL FIFTEEN COALS

Mine	Seam	Moisture %	Sulfur %	Ash %	BTU				Fixed Carbon		Volatile Matter		EPA Standard % Sulfur	Class
					Moist	Dry	Moist Mineral Matter Free	Dry Mineral Matter Free	Dry	Dry Mineral Matter Free	Dry	Dry Mineral Matter Free		
Edna	Wadge	8.41	0.75	9.13	11216	12246	12458	13602	50.22	55.84	40.65	44.16	0.73	II-5
Navajo	Nos. 6, 7, 8	11.07	0.81	25.29	8937	10050	12316	13849	39.20	54.09	35.51	45.91	0.60	II-5
Belle Ayr	Roland-Smith	19.14	0.76	7.55	9731	12034	10601	13111	45.34	49.47	47.11	50.53	0.72	II-5/ III-1
Colstrip	Rosebud	20.41	1.01	10.38	9225	11591	10398	13065	46.53	52.56	43.09	47.44	0.70	III-2
Weldon	Des Moines No. 1	13.29	6.39	15.74	10197	11760	12427	14331	43.64	53.70	40.62	46.30	0.71	II-5
Eagle No. 2	Illinois No. 5	3.31	4.29	26.53	10216	10566	14498	14994	39.17	55.85	34.30	44.15	0.63	II-3
Orient No. 6	Herrin No. 6	3.51	1.66	22.51	10771	11163	14294	14814	45.82	60.94	31.67	39.06	0.67	II-3
Camp Nos. 1 & 2	Seam No. 9	3.99	4.51	21.13	10662	11105	13971	14552	43.01	56.67	35.86	43.33	0.67	II-4
Walker	Upper Kittanning	2.07	0.71	16.67	12341	12602	15079	15398	64.44	78.83	18.89	21.17	0.76	II-1
Egypt Valley No. 21	Pittsburgh No. 8	2.07	6.55	25.29	10375	10594	14543	14851	38.59	54.44	36.12	45.56	0.64	II-3
No. 1	Mason	2.22	3.12	11.39	12764	13054	14664	14997	49.70	57.26	38.91	42.74	0.78	II-3
Jane Nos. 1 & 2	Lower Freeport	1.17	1.85	21.75	11792	11932	15498	15682	48.18	63.45	30.07	36.55	0.72	II-3
Fox	Lower Kittanning	1.83	3.83	13.55	12736	12973	15066	15347	48.12	57.11	38.33	42.89	0.78	II-3
Warwick	Sewickley	1.50	1.37	40.47	8483	8612	15150	15381	31.76	56.82	27.77	43.18	0.52	II-3
Humphrey No. 7	Pittsburgh No. 8	1.63	2.58	9.88	13409	13631	15106	15356	52.46	59.23	37.66	40.77	0.82	II-3

Class:
- II-1, Bituminous - Low Volatile
- II-2, Bituminous - Medium Volatile
- II-3, Bituminous - High Volatile A
- II-4, Bituminous - High Volatile B
- II-5, Bituminous - High Volatile C
- III-1, Subbituminous A
- III-2, Subbituminous B

Table B-3

COAL RANKING DATA - PYRITIC SULFUR EXTRACTIONS
FINAL TWENTY COALS

Mine	Seam	Moisture %	Sulfur %	Ash %	BTU				Fixed Carbon		Volatile Matter		EPA Standard % Sulfur	Class
					Moist	Dry	Moist Mineral Matter Free	Dry Mineral Matter Free	Dry	Dry Mineral Matter Free	Dry	Dry Mineral Matter Free		
Muskingum	Meigs Creek No. 9	3.36	3.22	16.05	11189	11578	13632	14106	47.00	57.50	36.95	42.50	0.69	II-4
Powhattan No. 4	Pittsburgh No. 8	2.10	2.04	32.12	9281	9480	14300	14607	38.60	59.66	29.28	40.34	0.57	II-3
Isabella	Pittsburgh	1.57	0.72	35.72	9166	9312	14960	15199	40.27	65.81	24.01	34.19	0.56	II-3
Mathies	Pittsburgh	2.15	0.94	36.43	8830	9024	14605	14925	38.06	63.05	25.51	36.95	0.54	II-3
Williams	Pittsburgh	1.28	1.74	9.16	13413	13587	14948	15142	52.06	58.10	38.78	41.90	0.82	II-3
Robinson Run	Pittsburgh	0.96	2.20	7.63	13632	13764	14933	15078	57.16	62.76	35.21	37.24	0.83	II-3
Shoemaker	Pittsburgh	1.51	1.87	28.87	10003	10156	14617	14841	41.33	60.55	29.80	39.45	0.61	II-3
Delmont	Upper Freeport	0.77	0.96	20.44	12015	12108	15462	15582	49.75	64.09	29.81	35.91	0.73	II-3
Marion	Upper Freeport	1.84	0.68	22.61	11504	11720	15252	15538	52.08	69.11	25.31	30.89	0.70	II-2
Lucas	Middle Kittanning	3.88	0.89	6.32	13345	13884	14351	14930	58.53	63.01	35.15	36.99	0.83	II-3
Bird No. 3	Lower Kittanning	0.84	0.80	24.17	11403	11500	15470	15601	58.26	79.15	17.57	20.85	0.69	II-1
Martinka	Lower Kittanning	1.84	0.58	43.46	7988	8138	15090	15373	34.41	65.07	22.13	34.93	0.49	II-3
Meigs	Clarion 4A	4.77	1.94	20.38	10535	11063	13570	14250	44.35	57.28	35.27	42.72	0.66	II-4
Dean	Dean	1.06	2.08	13.66	12529	12663	14773	14932	52.08	61.55	34.26	38.45	0.76	II-3
Kopperston	Campbell Creek	1.38	0.61	25.53	11184	11340	15470	15687	46.78	64.76	27.69	35.24	0.68	II-3
Harris Nos. 1&2	Eagle & No. 2 Gas	1.72	0.77	16.46	12340	12556	15039	15302	52.76	64.36	30.78	35.64	0.75	II-3
North River	Corona	1.57	0.93	42.84	8192	8323	15306	15550	33.42	62.53	23.74	37.47	0.50	II-3
Homestead	No. 11	5.41	2.38	11.50	11602	12266	13311	14072	52.58	60.53	35.92	39.47	0.74	II-4
Ken	No. 9	4.76	2.78	9.44	12085	12689	13533	14209	54.26	60.99	36.30	39.01	0.76	II-4
Star	No. 9	6.13	2.46	8.58	11875	12650	13148	14006	56.43	62.72	34.99	37.28	0.76	II-4

Class:

II-1, Bituminous - Low Volatile
II-2, Bituminous - Medium Volatile
II-3, Bituminous - High Volatile A
II-4, Bituminous - High Volatile B

Table B-4

COAL RANKING DATA - PYRITIC SULFUR EXTRACTIONS

INITIAL FIFTEEN COALS

Mine	Seam	Moisture %	Sulfur %	Ash %	BTU				Fixed Carbon		Volatile Matter		EPA Standard % Sulfur	Class
					Moist	Dry	Moist Mineral Matter Free	Dry Mineral Matter Free	Dry	Dry Mineral Matter Free	Dry	Dry Mineral Matter Free		
Edna	Wadge	8.41	1.14	6.77	11175	12201	12077	13186	50.38	55.08	42.35	44.92	0.73	II-5
Navajo	Nos. 6,7,8	11.07	0.76	20.53	8924	10035	11479	12908	43.65	56.24	35.82	43.76	0.60	II-5/ III-1
Belle Ayr	Roland-Smith	19.14	0.82	3.37	9315	11520	9670	11958	49.61	51.60	47.02	48.40	0.69	III-2
Colstrip	Rosebud	20.41	0.69	5.17	9010	11321	9545	11993	52.38	55.59	42.45	44.41	0.68	III-2
Weldon	Des Moines No. 1	13.29	2.34	6.43	10833	12493	11677	13467	54.96	59.51	38.61	40.49	0.75	II-5
Eagle No. 2	Illinois No. 5	3.31	2.12	19.80	11024	11401	14096	14579	45.70	58.60	34.50	41.40	0.68	II-3
Orient No. 6	Herrin No. 6	3.51	1.40	18.85	10647	11034	13410	13898	49.23	62.15	31.92	37.85	0.66	II-4
Camp Nos. 1 and 2	Seam No. 9	3.99	2.77	15.77	11272	11740	13669	14238	47.78	58.16	36.45	41.84	0.70	II-4
Egypt Valley No. 21	Pittsburgh No. 8	2.07	2.89	18.86	11268	11506	14253	14554	43.06	54.62	38.08	45.38	0.69	II-3
No. 1	Mason	2.22	1.62	8.50	13045	13341	14416	14743	53.87	59.63	37.63	40.37	0.80	II-3
Jane Nos. 1 and 2	Lower Freeport	1.17	0.67	17.99	12272	12417	15259	15440	51.65	64.27	30.36	35.73	0.75	II-3
Fox	Lower Kittanning	1.83	1.64	9.72	12933	13174	14504	14775	51.97	58.38	38.31	41.62	0.79	II-3
Warwick	Sewickley	1.50	0.82	35.32	9225	9365	14956	15184	38.07	61.80	26.61	38.20	0.56	II-3
Humphrey No. 7	Pittsburgh No. 8	1.63	1.49	6.97	13722	13949	14890	15137	55.99	60.85	37.04	39.15	0.84	II-3

Class:
II-1, Bituminous-Low Volatile (lvb)
II-2, Bituminous-Medium Volatile (mvb)
II-3, Bituminous-High Volatile A (hvAb)
II-4, Bituminous-High Volatile B (hvBb)
III-1, Subbituminous A
III-2, Subbituminous B

Table B-5

COMPUTER PROGRAM FOR DETERMINING THE RANK OF COAL

```
      PROGRAM RANK (INPUT,OUTPUT,TAPE6)
C     CLASSIFICATION OF COALS BY RANK
      REWIND 6
      PRINT 67
   67 FORMAT (*PRINTOUT IS SAVED ON TAPE 6*)
    1 PRINT 9
    9 FORMAT (*INPUT COAL NAME OR NUMBER*)
      READ 8,Q,O,P,M,PP,MM
    8 FORMAT (A8,A8,A8,A8,A8,A8)
      PRINT 2
    2 FORMAT (*INPUT SULFUR, ASH, BTU, VOLATILE MATTER, AND MOISTURE*)
      ACCEPT SULFUR,ASH,BTUD,VM,AMOIST
      FC=100-(ASH+VM)
      BTU=BTUD*((100.-AMOIST)/100.)
      DRYFC=((FC-0.15*SULFUR)/(100.-(1.08*ASH+0.55*SULFUR)))*100.
      DRYVM=100.-DRYFC
      WETBTU=((BTU-50*SULFUR)/(100.-(1.08*ASH+0.55*SULFUR)))*100.
      DRYBTU=WETBTU/((100.-AMOIST)/100.)
C     WTCOL=POUNDS COAL PER 1.0E+06 DRY BASIS BTU
      WTCOL=1.0E+06/BTUD
C     WTSUL=POUNDS SULFUR PER 1.0E+06 DRY BASIS BTU
      WTSUL=WTCOL*SULFUR/100.
C     EPASUL=PERCENT SULFUR TO MEET EPA STANDARD OF 0.6
C     POUNDS SULFUR PER 1.0E+06 BTU
      EPASUL=SULFUR*0.60/WTSUL
      WRITE (6,700)
      WRITE (6,8) Q,O,P,M
      WRITE (6,6) AMOIST,BTU
      WRITE (6,3) SULFUR,ASH,BTUD,FC,VM
      WRITE (6,4) DRYFC,DRYVM,DRYBTU,WETBTU
      WRITE (6,7) EPASUL
      WRITE (6,5)
      IF (GO)  55,222,222
  222 PRINT 700
      PRINT 8,Q,O,P,M
      PRINT 6, AMOIST,BTU
      PRINT 3, SULFUR, ASH, BTUD, FC, VM
    6 FORMAT (*MOISTURE=*,F5.2,*%, MOISTBTU=*,F6.0)
    3 FORMAT (*SULFUR=*,F5.2,*%, ASH=*,F6.2,*%, BTU=*,F6.0,/*FIXED*
     1* CARBON=*,F6.2,*%, VOLATILE MATTER=*,F6.2,*%*)
      PRINT 4, DRYFC,DRYVM,DRYBTU,WETBTU
    4 FORMAT (*DRY MINERAL MATTER FREE FIXED CARBON=*,F6.2,*%*/
     1*DRY MINERAL MATTER FREE VOLATILE MATTER=*,F6.2,*%*/
     2*DRY MINERAL MATTER FREE BTU=*,F6.0/
     3*MOIST MINERAL MATTER FREE BTU=*,F6.0)
      PRINT 7, EPASUL
    7 FORMAT (*EPA STANDARD-% SULFUR=*,F4.2,*%*)
   55 PRINT 5
    5 FORMAT (*RANK=*)
C       RANK SORTING
        IF (DRYFC-98.) 11,10,10
   11 IF (DRYFC-92.) 12,20,20
   12 IF (DRYFC-86.) 13,30,30
   13 IF (DRYFC-78.) 14,40,40
   14 IF (DRYFC-69.) 15,50,50
   15 IF (WETBTU-14000.) 16,60,60
   16 IF (WETBTU-13000.) 17,70,70
   17 IF (WETBTU-11500.) 18,80,80
   18 IF (WETBTU-10500.) 19,90,90
   19 IF (WETBTU-9500.) 200,100,100
  200 IF (WETBTU-8300.) 22,110,110
   22 IF (WETBTU-6300.) 23,120,120
   23 IF(WETBTU-6300.) 130,10,10
   10 PRINT 1111
      WRITE (6,1111)
      GO TO 1000
   20 PRINT 21
      WRITE (6,21)
      GO TO 1000
   30 PRINT 31
      WRITE (6,31)
      GO TO 1000
   40 PRINT 41
      WRITE (6,41)
      GO TO 1000
   50 PRINT 51
      WRITE (6,51)
      GO TO 1000
   60 PRINT 61
      WRITE (6,61)
      GO TO 1000
   70 PRINT 71
      WRITE (6,71)
      GO TO 1000
   80 PRINT 81
      WRITE (6,81)
      GO TO 1000
   90 PRINT 91
      WRITE (6,91)
      GO TO 1000
  100 PRINT 101
      WRITE (6,101)
      GO TO 1000
  110 PRINT 111
      WRITE (6,111)
      GO TC 1000
  120 PRINT 121
      WRITE (6,121)
       GO TO 1000
  130 PRINT 131
      WRITE (6,131)
 1111 FORMAT (*CLASS I-1, META-ANTHRACITE*)
   21 FORMAT (*CLASS I-2, ANTHRACITE*)
   31 FORMAT (*CLASS I-3, SEMIANTHRACITE*)
   41 FORMAT (*CLASS II-1, BITUMINOUS-LOW VOLATILE*)
   51 FORMAT (*CLASS II-2, BITUMINOUS-MFDIUM VOLATILE*)
   61 FORMAT (*CLASS II-3, BITUMINOUS-HIGH VOLATILE A*)
   71 FORMAT (*CLASS II-4, BITUMINOUS-HIGH VOLATILE B*)
   81 FORMAT (*CLASS II-5, BITUMINOUS-HIGH VOLATILE C*)
   91 FORMAT (*CLASS II-5, BITUMINOUS-HIGH VOLATILE C,*
     1*AGGLOMERATING*/*CLASS III-1,SUBBITUMINOUS A,NONAGGLOMERATING*)
  101 FORMAT (*CLASS III-2, SUBBITUMINOUS B*)
  111 FORMAT (*CLASS III-3, SUBBITUMINOUS C*)
  121 FORMAT (*CLASS IV-1, LIGNITE A*)
  131 FORMAT (*CLASS IV-2, LIGNITE B*)
 1000 PRINT 700
  700 FORMAT (//)
      PRINT 68
   68 FORMAT (*GO?=1*)
      ACCEPT GO
      IF (GO) 1,69,1
   69 PRINT 700
      END
```

APPENDIX C

UNTREATED COAL ANALYSES DATA

Table C-1

UNTREATED COAL ANALYSES

MUSKINGUM, POWHATTAN NO. 4, ISABELLA AND MATHIES MINES

Mine, Seam, and Location	Sample	As Received Basis	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
		Moisture % w/w	Total	Pyritic	Sulfate	Organic	Ash	Volatiles	Fixed Carbon	Heat Content btu
Muskingum Mine	A	3.32	5.96	3.64	0.08	2.24	21.58	37.49	40.93	11030
Meigs Creek No.9	B	3.40	6.10	3.66	0.05	2.39	21.75	35.97	42.28	10981
Morgan County	C	3.35	6.18	3.65	0.04	2.49	21.72	35.63	42.65	11033
Ohio	Average	3.36	6.08	3.65	0.06	2.37	21.68	36.36	41.96	11014
	Std. Dev.	±.040	±0.111	±0.010	±.021	±.113	±.091	±.990	±.994	±29.2
Powhattan No.4	A	2.16	4.08	2.51	0.18	1.39	37.07	28.66	34.27	8522
Pittsburgh No.8	B	1.85	4.08	2.57	0.21	1.30	37.67	29.03	33.30	8520
Monroe County	C	2.29	4.21	2.63	0.19	1.39	36.77	29.35	33.88	8769
East Ohio	Average	2.10	4.12	2.57	0.19	1.36	37.17	29.01	33.82	8603
	Std. Dev.	±.225	±.075	±.060	±.015	±.097	±.458	±.345	±.573	±143.2
Isabella Mine	A	1.66	1.54	1.14	0.04	0.36	42.37	24.71	32.92	8223
Pittsburgh Seam	B	1.56	1.58	1.06	0.04	0.48	42.18	24.62	33.20	8197
Fayette County	C	1.50	1.58	1.00	0.04	0.54	42.12	24.74	33.14	8227
Pennsylvania	Average	1.57	1.57	1.07	0.04	0.46	42.22	24.69	33.09	8216
	Std. Dev.	±.081	±.023	±.070	±.00	±.074	±.131	±.062	±.145	±16.2
Mathies Mine	A	2.31	1.45	0.98	0.04	0.43	41.03	24.41	34.56	8289
Pittsburgh Seam	B	2.18	1.44	1.05	0.04	0.35	41.03	24.43	34.54	8028
Washington County	C	2.15	1.48	1.11	0.04	0.33	40.96	24.75	34.29	8146
Pennsylvania	Average	2.15	1.46	1.05	0.04	0.37	41.01	24.53	34.46	8154
	Std. Dev.	±.025	±.021	±.065	±.00	±.068	±.040	±.191	±.150	±130.6

Table C-2

UNTREATED COAL ANALYSES
WILLIAMS, ROBINSON RUN, SHOEMAKER AND DELMONT MINES

Mine, Seam, and Location	Sample	As Received Basis	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
		Moisture % w/w	Total	Pyritic	Sulfate	Organic	Ash	Volatiles	Fixed Carbon	Heat Content btu
Williams Mine	A	1.33	3.49	2.18	0.04	1.27	13.19	38.50	48.31	12947
Pittsburgh Seam	B	1.25	3.48	2.21	0.05	1.22	13.11	38.47	48.42	13069
Marion County	C	1.25	3.47	2.30	0.04	1.13	13.25	38.94	47.81	13025
West Virginia	Average	1.28	3.48	2.23	0.04	1.21	13.18	38.64	48.18	13013
	Std. Dev.	±.046	±.010	±.062	±.006	±.063	±.070	±.263	±.272	±61.6
Robinson Run Mine	A	0.93	4.36	2.88	0.06	1.42	13.43	39.01	47.56	12912
Pittsburgh Seam	B	0.94	4.42	2.70	0.06	1.66	13.20	39.15	47.65	13022
Harrison County	C	1.00	4.37	3.08	0.06	1.23	13.45	38.49	48.06	12951
West Virginia	Average	0.96	4.38	2.89	0.06	1.43	13.36	38.88	47.76	12962
	Std. Dev.	±.038	±.032	±.190	±.00	±.193	±.139	±.348	±.375	±56.8
Shoemaker Mine	A	1.49	3.51	2.09	0.05	1.37	33.61	30.94	35.45	9512
Pittsburgh Seam	B	1.54	3.52	2.29	0.05	1.18	33.48	31.10	35.42	9486
Marshall County	C	1.50	3.50	2.20	0.05	1.25	33.36	31.35	35.29	9488
West Virginia	Average	1.51	3.51	2.19	0.05	1.27	33.48	31.13	35.39	9495
	Std. Dev.	±.025	±.010	±.100	±.00	±.100	±.125	±.207	±.242	±14.5
Delmont Mine	A	0.81	4.86	4.61	0.08	0.17	27.40	28.45	44.15	11044
Upper Freeport	B	0.77	4.91	4.53	0.08	0.30	26.92	28.08	45.00	10981
Westmoreland County	C	0.74	4.90	4.54	0.08	0.28	27.22	28.47	44.31	11011
Pennsylvania	Average	0.77	4.89	4.56	0.08	0.25	27.18	28.33	44.49	11012
	Std. Dev.	±.035	±.025	±.044	±.00	±.051	±.242	±.220	±.327	±31.5

Table C-3

UNTREATED COAL ANALYSES

MARION, LUCAS, BIRD NO. 3, AND MARTINKA MINES

Mine, Seam, and Location	Sample	As Received Basis	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
		Moisture % w/w	Total	Pyritic	Sulfate	Organic	Ash	Volatiles	Fixed Carbon	Heat Content btu
Marion Mine	A	1.71	1.37	0.92	0.00	0.45	26.46	24.70	48.84	11076
Upper Freeport Seam	B	1.69	1.34	0.89	0.03	0.42	26.44	24.59	48.97	11039
Indiana County	C	2.13	1.39	0.89	0.03	0.47	26.31	24.06	49.63	11024
Pennsylvania	Average	1.84	1.37	0.90	0.02	0.45	26.40	24.45	49.15	11046
	Std. Dev.	±.248	±.025	±.017	±.017	±.035	±.081	±.342	±.423	±26.8
Lucas Mine	A	3.89	1.93	1.51	0.05	0.37	8.66	35.48	55.86	13520
Middle Kittanning	B	3.88	1.73	1.35	0.05	0.33	8.78	35.30	55.92	13443
Columbiana County	C	3.86	1.71	1.40	0.05	0.26	8.61	35.12	56.27	13390
Ohio	Average	3.88	1.79	1.42	0.05	0.32	8.68	35.30	56.02	13451
	Std. Dev.	±.015	±.122	±.082	±.00	±.147	±.087	±.180	±.221	±65.4
Bird No.3 Mine	A	0.88	3.09	2.82	0.05	0.22	30.12	16.19	53.69	10554
Lower Kittanning	B	0.82	3.19	2.94	0.05	0.20	30.58	16.09	53.33	10495
Sommerset County	C	0.83	3.15	2.85	0.05	0.25	29.99	16.25	53.76	10600
Pennsylvania	Average	0.84	3.14	2.87	0.05	0.22	30.23	16.18	53.59	10550
	Std. Dev.	±.032	±.050	±.062	±.00	±.080	±.310	±.081	±.320	±52.6
Martinka Mine	A	1.50	1.93	1.59	0.10	0.24	49.60	21.94	28.46	7548
Lower Kittanning	B	2.30	1.96	1.62	0.09	0.25	49.65	21.66	28.69	7550
Logan or Mingo	C	1.70	1.98	1.63	0.09	0.26	49.66	21.54	28.78	7559
West Virginia	Average	1.84	1.96	1.61	0.09	0.26	49.64	21.60	28.76	7552
	Std. Dev.	±.428	±.025	±.021	±.006	±.033	±.040	±.085	±.094	±5.9

Table C-4

UNTREATED COAL ANALYSES

MEIGS, DEAN, KOPPERSTON NO. 2, AND HARRIS NOS. 1 & 2 MINES

Mine, Seam, and Location	Sample	As Received Basis	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
		Moisture % w/w	Total	Pyritic	Sulfate	Organic	Ash	Volatiles	Fixed Carbon	Heat Content btu/lb
Meigs Mine	A	4.77	3.69	2.22	0.06	1.41	26.49	35.46	38.05	10240
Clarion 4A Seam	B	4.79	3.73	2.19	0.06	1.48	26.39	34.61	39.00	10255
Meigs County	C	4.74	3.76	2.16	0.05	1.55	26.71	34.70	38.59	10243
Ohio	Average	4.77	3.73	2.19	0.06	1.48	26.53	34.92	38.55	10246
	Std. Dev.	±.025	±.035	±.030	±.006	±.046	±.164	±.467	±.495	±7.9
Dean Mine	A	1.13	4.11	2.64	0.15	1.32	17.42	39.09	45.49	12153
Dean Seam	B	1.08	4.10	2.69	0.15	1.26	16.97	36.52	46.51	12088
Scott County	C	.96	4.06	2.52	0.15	1.39	17.46	35.13	47.41	12080
Tennessee	Average	1.06	4.09	2.62	0.15	1.32	17.28	36.91	45.81	12107
	Std. Dev.	±.087	±.026	±.087	±0.00	±.091	±0.272	±2.01	±2.03	±40.0
Kopperston Mine	A	1.40	0.95	0.49	0.04	0.42	30.10	23.99	45.91	10941
Campbell Creek Seam	B	1.40	0.86	0.44	0.04	0.38	30.15	23.69	46.16	10986
Wyoming County	C	1.34	0.93	0.48	0.02	0.43	30.20	23.99	45.81	10945
West Virginia	Average	1.38	0.91	0.47	0.03	0.41	30.15	23.89	45.96	10957
	Std. Dev.	±.035	.047	±.026	±.012	±.055	±0.050	±0.173	±0.180	±24.9
Harris Nos. 1 & 2 Mines	A	1.74	1.01	0.52	0.03	0.46	18.62	26.76	54.62	1237[illegible]
Eagle and No. 2 Gas Seams	B	1.72	1.00	0.45	0.03	0.52	18.69	26.71	54.60	12434
Boone County,	C	1.71	1.00	0.50	0.03	0.47	18.58	27.12	54.30	12439
West Virginia	Average	1.72	1.00	0.49	0.03	0.48	18.63	26.86	54.51	12414
	Std. Dev.	±.015	±.006	±.036	±.00	±.036	±0.056	±0.224	±0.231	±38.5

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Table C-5
UNTREATED COAL ANALYSES
NORTH RIVER, HOMESTEAD, KEN AND STAR MINES

Mine, Seam, and Location	Sample	As Received Basis	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
		Moisture % w/w	Total	Pyritic	Sulfate	Organic	Ash	Volatiles	Fixed Carbon	Heat Content btu/lb
North River Mine	A	1.61	2.07	1.42	0.07	0.58	49.21	23.26	27.53	7715
Corona Seam	B	1.57	2.06	1.44	0.07	0.55	49.25	23.16	27.59	7692
Jefferson County	C	1.54	2.04	1.40	0.07	0.57	49.30	23.16	27.59	7673
Alabama	Average	1.57	2.06	1.42	0.07	0.57	49.25	23.19	27.56	7693
	Std. Dev.	±.035	±.015	±.020	±.00	±.025	±.045	±.058	±.073	±21.
Homestead Mine	A	5.47	4.47	3.12	0.10	1.26	16.54	32.77	50.69	11966
No. 11 Seam	B	5.39	4.45	3.17	0.10	1.21	16.56	33.80	49.64	11962
Ohio County	C	5.38	4.46	3.05	0.11	1.30	16.57	32.85	50.58	11878
West Kentucky	Average	5.41	4.46	3.11	0.11	1.25	16.56	33.14	50.30	11935
	Std. Dev.	±.049	±.010	±.049	±.006	±.051	±.150	±.573	±.592	±49.7
Ken Mine	A	4.77	4.86	2.83	0.26	1.72	15.06	34.30	50.64	12127
No. 9 Seam	B	4.79	4.79	2.83	0.25	1.72	15.03	35.63	49.34	12063
Ohio County	C	4.71	4.84	2.89	0.26	1.69	15.14	35.85	49.01	12107
West Kentucky	Average	4.76	4.83	2.85	0.26	1.72	15.08	35.26	49.66	12099
	Std Dev.	±.042	±.036	±.038	±.006	±.053	±.057	±.839	±.841	±32.7
Star Mine	A	6.16	4.30	2.50	0.27	1.58	13.89	35.14	56.97	12275
No. 9 Seam	B	6.14	4.32	2.60	0.22	1.50	13.84	33.56	52.60	12309
Hopkins County	C	6.09	4.35	2.70	0.22	1.43	13.98	33.12	52.90	12340
West Kentucky	Average	6.13	4.32	2.60	0.24	1.50	13.90	33.94	52.16	12308
	Std. Dev.	±.038	±.025	±.100	±.029	±.075	±.071	±1.062	±1.064	±35.5

APPENDIX D

PYRITIC SULFUR REMOVAL DATA

NOTE: The complete general procedure used to treat the coals is contained in Section 4.3 of this report. Variables such as mesh, reaction time, and leach numbers and times are listed in the tables. Numbers in parentheses are not considered valid for various reasons but are included for completeness. Averages are included only where appropriate.

Table D-1

PYRITIC SULFUR REMOVAL DATA

MUSKINGUM, POWHATTAN NO. 4, ISABELLA AND MATHIES MINES

Mine, Seam, and Location	Mesh	Total Rxn. Time	Leach Changes		Run Number		Dry Forms of Sulfur, % w/w			Dry Proximate Analysis, % w/w			
			Number	Time (hrs)		Total Sulfur	Pyritic	Sulfate	Organic	Ash	Volatile Matter	Fixed Carbon	btu/lb
Muskingum Mine	150	23	1	5.0	1	3.24	0.24 0.27	0.18	2.80	16.11	36.96	46.93	11546
Meigs Creek No. 9	150	23	1	5.0	2	3.20	0.20 0.26	0.16	2.81	15.99	36.94	47.07	11611
Morgan County			Treated Average Std. Dev.		1-2	3.22 ±.028	0.24 ±.031	0.17 ±.014	2.81 ±044	16.05 ±.085	36.95 ±.014	47.00 ±.086	11578 ±46.0
Ohio			Initial Average Std. Dev.		A-C	6.08 ±.111	3.65 ±.010	0.06 ±.021	2.37 ±.113	21.68 ±.990	36.36 ±.990	41.96 ±.994	11014 ±29.2
Powhattan No. 4	100	23	1	9.0	1	2.04	0.41 0.39	0.11	1.53	31.76	29.26	38.98	9529
Pittsburgh No. 8	100	23	1	9.0	2	2.03	0.50 0.47	0.13	1.42	32.48	29.29	38.23	9431
Monroe County			Treated Average Std. Dev.		1-2	2.04 ±.007	0.44 ±.051	0.12 ±.014	1.48 ±.053	32.13 ±.509	29.28 ±.021	38.60 ±.509	9480 ±69.3
East Ohio			Initial Average Std. Dev.		A-C	4.12 ±.075	2.57 ±.060	0.19 ±.015	1.36 ±.097	37.17 ±.458	29.01 ±.345	33.82 ±.573	8603 ±143.2
	200	23	1	4.5	3	1.94	0.04	0.10	1.80				
Isabella Mine	100	23	0	---	1	0.71	0.05 0.07	0.00	0.51	35.61	24.35	40.04	9321
Pittsburgh Seam	100	23	0	---	2	0.72	0.06 0.07	0.01	0.41	35.83	23.67	40.50	9302
Fayette County			Treated Average Std. Dev.		1-2	0.72 ±.007	0.06 ±.010	0.01 ±.007	0.65 ±.014	35.72 ±.156	24.01 ±.481	40.27 ±.506	9312 ±13.4
Pennsylvania			Initial Average Std. Dev.		A-C	1.57 ±.023	1.07 ±.070	0.04 ±0.00	0.46 ±.074	42.22 ±.131	24.69 ±.062	33.09 ±.145	8216 ±130.6
Mathies Mine	150	23	0	---	1	0.95	0.08 0.02	0.10	0.80	36.16	26.11	37.73	9071
Pittsburgh Seam	150	23	0	---	2	0.92	0.08 0.02	0.10	0.87	36.70	24.91	38.39	8978
Washington County			Treated Average Std. Dev.		1-2	0.94 ±.021	0.05 ±.035	0.10 ±.00	0.79 ±.041	36.43 ±.382	25.51 ±.849	38.06 ±.931	9024 ±65.8
Pennsylvania			Initial Average Std. Dev.		A-C	1.46 ±.021	1.05 ±.065	0.04 ±.00	0.37 ±.068	41.01 ±.040	24.53 ±.191	34.66 ±.150	8154 ±130.6

Table D-2

PYRITIC SULFUR REMOVAL DATA

WILLIAMS, ROBINSON RUN, SHOEMAKER AND DELMONT MINES

Mine, Seam, and Location	Mesh	Total Rxn. Time	Leach Changes		Run Number	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
			Number	Time (hrs)		Total Sulfur	Pyritic	Sulfate	Organic	Ash	Volatile Matter	Fixed Carbon	btu/lb
Williams Mine	100	23	1	10	1	1.76	0.25 0.32	0.06	1.42	9.19	39.35	51.46	13610
Pittsburgh Seam	100	23	1	10	2	1.72	0.32 0.27	0.06	1.36	9.12	38.22	52.66	13564
Marion County			Treated Average Std. Dev.		1-2	1.74 ±.028	0.29 ±.036	0.06 ±.00	1.39 ±.046	9.16 ±.049	38.78 ±.779	52.06 ±.801	13587 ±32.5
West Virginia			Initial Average Std. Dev.		A-C	3.48 ±.010	2.23 ±.062	0.04 ±.006	1.21 ±.063	13.18 ±.070	38.64 ±.263	48.18 ±.272	13013 ±61.6
	150	23			3	1.80	0.10	0.09	1.55	8.58	36.26	55.16	13377
Robinson Run Mine	150	23.5	1	6	1	2.20	0.09 0.09	0.00	2.11	7.47	35.31	57.22	13793
Pittsburgh Seam	150	23.5	1	6	1	2.19	0.07 0.07	0.00	2.12	7.79	35.11	57.10	13736
Harrison County			Treated Average Std. Dev.		1-2	2.20 ±.007	0.08 ±.012	0.00 ±.00	2.12 ±.014	7.63 ±.226	35.21 ±.141	57.16 ±.266	13764 ±40.3
West Virginia			Initial Average Std. Dev.		A-C	4.38 ±.032	2.89 ±.190	0.06 ±.00	1.43 ±.193	13.36 ±.139	38.88 ±.348	47.76 ±.375	12962 ±55.8
Shoemaker Mine	100	23	1	7	1	1.78	0.34 0.38	0.07	1.35	28.50	29.95	41.55	10131
Pittsburgh Seam	100	23	1	7	2	1.96	0.55 0.55	0.08	1.33	29.24	29.66	41.10	10180
Marshall County			Treated Average Std. Dev.		1-2	1.87 ±.127	0.46 ±.111	0.08 ±.007	1.34 ±.169	28.87 ±.523	29.80 ±.205	41.33 ±.562	10156 ±34.6
West Virginia			Initial Average Std. Dev.		A-C	3.51 ±.010	2.19 ±.100	0.05 ±.00	1.27 ±.100	33.48 ±.125	31.13 ±.207	35.39 ±.242	9495 ±14.5
	150	23	1	4.5	3	1.73	0.08	0.11	1.70	27.24	31.58	41.18	10195
Delmont Mine	200	23	1	6	1	0.90	0.16 0.11	0.05	0.71	20.14	29.95	49.91	12150
Upper Freeport	200	23	1	6	2	1.02	0.27 0.30	0.07	0.67	20.74	29.67	49.59	12067
Westmoreland County			Treated Average Std. Dev.		1-2	0.96 ±.085	0.21 ±.090	0.06 ±.014	0.69 ±.125	20.44 ±.424	29.81 ±.198	49.75 ±.468	12108 ±58.7
Pennsylvania			Initial Average Std. Dev.		A-C	4.89 ±.025	4.56 ±.044	0.08 ±.000	0.25 ±.051	27.18 ±.242	28.33 ±.220	44.49 ±.327	11012 ±31.5

Table D-3

PYRITIC SULFUR REMOVAL DATA

MARION, LUCAS, BIRD NO. 3, AND MARTINKA MINES

Mine, Seam, and Location	Mesh	Total Rxn. Time	Leach Changes		Run Number	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
			Number	Time (hrs)		Total Sulfur	Pyritic	Sulfate	Organic	Ash	Volatile Matter	Fixed Carbon	Btu/lb
Marion Mine	100	23	0	---	1	0.77 0.76	0.04 0.06	0.04 0.05	0.69 0.65	22.59	25.17	52.24	11739
Upper Freeport Seam	100	23	0	---	2	0.57 0.62	0.03 0.04	0.05 0.09	0.49 0.49	22.63	25.45	51.92	11701
Indiana County			Treated Average Std. Dev.		1-2	0.68 ±.100	0.04 ±.013	0.06 ±.022	0.58 ±.103	22.61 ±.028	25.31 ±.198	52.08 ±.200	11720 ±26.9
Pennsylvania			Initial Average Std. Dev.		A-C	1.37 ±.025	0.90 ±.017	0.02 ±.017	0.45 ±.035	26.40 ±.081	24.45 ±.342	49.15 ±.423	11041 ±26.8
Lucas Mine	100	23	-	---	1	0.83	0.19 0.19	0.13 0.14	0.50	6.25	35.49	58.26	13922
Middle Kittanning	100	23	0	---	2	0.95	0.26 0.20	0.09 0.15	0.69	6.39	34.81	58.80	13845
Columbia County			Treated Average Std. Dev.		1-2	0.89 ±.085	0.21 ±.034	0.13 ±.026	0.55 ±.095	6.32 ±.099	35.15 ±.481	58.53 ±.491	13884 ±54.4
Ohio			Initial Average Std. Dev.		A-C	1.79 ±.122	1.42 ±.087	0.05 ±.00	0.32 ±.147	8.68 ±.087	35.30 ±.180	56.02 ±.221	13451 ±65.4
	150	23			3	0.63	0.07	0.15	0.41				
Bird No. 3 Mine	150	23	1	6	1	0.78	0.10 0.13	0.11	0.55	23.85	17.35	58.80	11532
Lower Kittanning	150	23	1	6	2	0.83	0.12 0.18	0.11	0.57	24.49	17.79	57.72	11468
Sommerset County			Treated Average Std. Dev.		1-2	0.80 ±.035	0.13 ±.034	0.11 ±.00	0.56 ±.049	24.17 ±.453	17.57 ±.311	58.26 ±.549	11500 ±45.3
Pennsylvania			Initial Average Std. Dev.		A-C	3.14 ±.050	2.87 ±.062	0.05 ±.00	0.22 ±.080	30.23 ±.310	16.18 ±.081	53.59 ±.320	10550 ±52.6
Martinka Mine	10C	23	0	---	1	0.59	0.13 0.13	0.09	0.37	43.44	22.20	34.36	8137
Lower Kittanning	100	23	0	---	2	0.57	0.12 0.12	0.07	0.38	43.47	22.06	34.47	8138
Logan or Mingo			Treated Average Std. Dev.		1-2	0.58 ±.014	0.12 ±.006	0.08 ±.014	0.38 ±.021	43.46 ±.021	22.13 ±.099	34.41 ±.101	8138 ±0.7
West Virginia			Initial Average Std. Dev.		A-C	2.06 ±.015	1.42 ±.020	0.07 ±.00	0.57 ±.025	49.25 ±.045	23.19 ±.058	27.56 ±.073	7693 ±21.0

Table D-4

PYRITIC SULFUR REMOVAL DATA

MEIGS, DEAN, KOPPERSTON, AND HARRIS NOS. 1 & 2 MINES

Mine, Seam, and Location	Mesh	Total Rxn. Time	Leach Changes		Run Number	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
			Number	Time (hrs)		Total Sulfur	Pyritic	Sulfate	Organic	Ash	Volatile Matter	Fixed Carbon	btu/lb
Meigs Mine	100	23	1	9	1	1.97	0.20 0.19	0.16	1.61	20.61	35.03	44.36	11022
Clarion 4A Seam	100	23	1	9	2	1.90	0.15 0.14	0.13	1.63	20.16	35.51	44.33	11104
Meigs County			Treated Average Std. Dev.		1-2	1.94 ±.049	0.17 ±.029	0.14 ±.021	1.63 ±.061	20.38 ±.318	35.27 ±.339	44.35 ±.465	11063 ±58.0
Ohio			Initial Average Std. Dev.		A-C	3.73 ±.035	2.19 ±.030	0.06 ±.006	1.48 ±.046	26.53 ±.164	34.92 ±.467	38.55 ±.495	10246 ±7.9
Dean Mine	150	23	0	---	1	2.08	0.20 0.13	0.17	1.75	13.72	33.66	52.62	12674
Dean Seam	150	23	0	---	2	2.07	0.19 0.18	0.15	1.74	13.59	34.85	51.56	12652
Scott County			Treated Average Std. Dev.		1-2	2.08 ±.007	0.17 ±.029	0.16 ±.014	1.75 ±.033	13.66 ±.092	34.26 ±.841	52.08 ±.846	12663 ±15.6
Tennessee			Initial Average Std. Dev.		A-C	4.09 ±.026	2.62 ±.087	0.15 ±.00	1.32 ±.091	17.28 ±.272	36.91 ±2.01	48.81 ±.2.03	12107 ±40.0
Kopperston Mine	100	13	0	---	1	0.63	0.02 0.03	0.07	0.54	25.56	27.42	47.02	11339
Campbell Creek Seam	100	13	0	---	2	0.59	0.02 0.08	0.08	0.46	25.50	27.96	46.54	11341
Wyoming County			Treated Average Std. Dev.		1-2	0.61 ±.028	0.04 ±.029	0.08 ±.007	0.49 ±.041	25.53 ±.042	27.69 ±.382	46.78 ±.384	11340 ±1.4
West Virginia			Initial Average Std. Dev.		A-C	0.91 ±.047	0.47 ±.026	0.03 ±.012	0.41 ±.055	30.15 ±.050	23.89 ±.173	45.96 ±.180	10957 ±24.9
Harris Nos. 1 & 2 Mines	100	23	0	---	1	0.77	0.02 0.04	0.06	0.68	16.33	31.60	52.07	12551
Eagle and No. 2 Gas Seams	100	23	0	--	2	0.77	0.02 0.10	0.07	0.64	16.59	29.96	53.45	12561
Boone County			Treated Average Std. Dev.		1-2	0.77 ±.00	0.04 ±.038	0.06 ±.007	0.67 ±.039	16.46 ±.184	30.78 ±1.16	52.76 ±1.18	12556 ±7.1
West Virginia			Initial Average Std. Dev.		A-C	1.00 ±.006	0.49 ±.036	0.03 ±.00	0.48 ±.036	18.63 ±.056	26.86 ±.224	54.51 ±.231	12414 ±38.5

Table D-5

PYRITIC SULFUR REMOVAL DATA

NORTH RIVER, HOMESTEAD, KEN, AND STAR MINES

Mine, Seam, and Location	Mesh	Total Rxn. Time	Leach Changes		Run Number	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
			Number	Time (hrs)		Total Sulfur	Pyritic	Sulfate	Organic	Ash	Volatile Matter	Fixed Carbon	btu/lb
North River Mine	100	23	0	---	1	0.92	0.19 0.13	0.09	0.67	42.68	23.85	33.47	8399
Corona Seam	100	23	0	---	2	0.94	0.15 0.10	0.09	0.73	43.00	23.62	33.38	8247
Jefferson County			Treated Average Std. Dev.		1-2	0.93 ±.014	0.14 ±.038	0.09 ±.00	0.70 ±.040	42.84 ±.226	23.74 ±.163	33.42 ±.279	8323 ±107.5
Alabama			Initial Average Std. Dev.		A-C	2.06 ±.015	1.42 .026	0.07 ±.00	0.57 ±.025	49.28 .045	23.19 ±.058	27.56 ±.073	7693 ±21.0
Homestead Mine	100	23	1	5.0	1	2.31	0.20 0.15	0.29	1.84	11.40	36.77	51.83	12301
No. 11 Seam	100	23	1	5.0	2	2.45	0.24 0.28	0.32	1.87	11.59	35.08	53.33	12231
Ohio County			Treated Average Std. Dev.		1-2	2.38 .099	0.22 ±.056	0.30 ±.021	1.86 ±.116	11.50 ±.134	35.92 ±1.20	52.58 ±1.21	12266 ±49.5
West Kentucky			Initial Average Std. Dev.		A-C	4.46 .010	3.11 .049	0.10 .011	1.25 .051	16.56 ±.150	33.14 .573	50.30 ±.592	11935 ±49.7
Ken Mine	100	23	1	5	1	2.82	0.28 0.34	0.27	2.24	9.46	36.62	53.92	12695
No. 9 Seam	100	23	1	5	2	2.75	0.21 0.27	0.24	2.27	9.42	35.97	54.61	12683
Ohio County			Treated Average Std. Dev.		1-2	2.78 ±.059	0.28 ±.021	0.26 ±.021	2.24 ±.043	9.44 ±.028	36.30 ±.460	[illegible]6 .461	12689 ±8.5
West Kentucky			Initial Average Std. Dev.		A-C	4.83 ±.036	2.85 ±.038	0.26 ±.006	1.72 ±.053	15.08 ±.057	35.26 ±.839	49.66 ±.841	12099 ±32.7
Star Mine	150	23	2	5 & 10	1	2.52	0.06 0.10	0.35	2.09	8.68	34.92	56.40	12646
No. 9 Seam	150	23	2	5 & 10	2	2.39	0.03 0.06	0.33	2.02	8.47	35.06	56.47	12655
Hopkins County			Treated Average Std. Dev.		1-2	2.46 ±.092	0.06 ±.029	0.34 ±.014	2.06 ±.097	8.58 ±.148	34.99 ±.099	56.43 ±.178	12650 ±6.4
West Kentucky			Initial Average Std. Dev.		A-C	4.32 ±.025	2.60 ±.100	0.24 ±.029	1.50 ±.075	13.90 ±.071	33.94 ±1.062	52.16 ±1.064	12308 ±35.5

TABLE D-6
PYRITIC SULFUR REMOVAL DATA

NAVAJO MINE

Mine, Seam and Location	Mesh	Total Rxn. Time	Leach Changes		Run Number	Dry Forms of Sulfur, % w/w				Dry Proximate Analysis, % w/w			
			Number	Time (hrs)		Total Sulfur	Pyritic	Sulfate	Organic	Ash	Volatile Matter	Fixed Carbon	btu/lb
Navajo Mine													
Nos. 6,7,8 Seam	100	23	2	5.0, 13.5	1-3	0.76	0.04	0.15	0.57	20.53	35.82	43.60	10033
San Juan County													
New Mexico	100	6	1	3	4	0.61	0.03	0.12	0.46	19.70	35.77	44.53	10353
			Initial Average		-	0.81	0.28	0.03	0.50	25.29	35.51	39.40	10050

*Includes Supplemental Run Data and Summary of Initial Data from Ref. 2.

APPENDIX E

WASHABILITY TABLES

NOTE: Coal washability results have been performed through standard flat and sink testing, discussed in Section 4.4

Central Ohio Coal Co.
Muskingum Mine - Meigs Creek #9 Seam
Morgan County, Ohio

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

TABLE E-1. 38.1 mm X 149μ ($1^1/_2$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	1.1	3.98	3.49	.68	1.1	3.98	3.49	.68	100.0	21.47	5.51	3.30
1.30	1.40	38.5	9.81	4.23	1.49	39.6	9.65	4.21	1.47	98.9	21.66	6.53	3.33
1.40	1.60	43.5	21.19	4.61	2.41	83.1	15.69	4.42	1.96	60.4	29.22	6.36	4.50
1.60	1.90	8.4	37.88	6.59	5.48	91.5	17.73	4.62	2.28	16.9	49.89	10.88	9.90
1.90		8.5	61.75	15.12	14.26	100.0	21.47	5.51	3.30	8.5	61.75	15.12	14.26
Head Sample[a]							22.23	5.49	3.41				
Fine[b]							27.40	5.27	3.04				

a) 38.1 mm x 149μ (1-1/2" x 100 mesh) = 99.0% of Raw Run of Mine Coal Crushed to 38.1 mm.

b) 149μ x 0 (100 mesh x 0) = 1.0% of Raw Run of Mine Coal Crushed to 38.1 mm.

TABLE E-2. 9.51 mm X 149μ ($^3/_8$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				Sulfur				Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	4.8	8.51	4.19	1.92	4.8	8.51	4.19	1.92	100.0	22.90	5.57	3.66
1.30	1.40	48.5	15.13	4.89	2.78	53.3	14.53	4.83	2.70	95.2	23.62	5.64	3.75
1.40	1.60	34.6	26.90	5.25	3.25	87.9	19.40	4.99	2.92	46.7	32.45	6.42	4.76
1.60	1.90	6.3	36.61	6.11	5.75	94.2	20.55	5.07	3.07	12.1	48.30	9.76	9.08
1.90		5.8	61.00	13.72	13.24	100.0	22.90	5.57	3.66	5.8	61.00	13.72	13.24
Head Sample[a]							22.39	5.61	3.41				
Fine[b]							22.96	5.56	3.28				

a) 9.51 mm x 149μ (3/8" x 100 mesh) = 94.2% of Raw Run of Mine Coal Crushed to 9.51 mm.

b) 149μ x 0 (100 mesh x 0) = 5.8% of Raw Run of Mine Coal Crushed to 9.51 mm.

TARLE E-3. 1.41 mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				Sulfur				Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	11.5	9.18	3.46	.82	11.5	9.18	3.46	.82	100.0	22.82	5.52	3.31
1.30	1.40	35.5	12.48	4.38	1.64	47.0	11.66	4.15	1.44	88.5	24.60	5.79	3.63
1.40	1.60	32.1	24.39	4.20	2.05	79.1	16.82	4.17	1.69	53.0	32.73	6.74	4.97
1.60	1.90	11.5	35.42	5.64	4.04	90.6	19.18	4.36	1.99	20.9	45.53	10.63	9.45
1.90		9.4	57.90	16.74	16.06	100.0	22.82	5.52	3.31	9.4	57.90	16.74	16.06
Head Sample[a]							22.52	5.60	3.40				

a) 1.41 mm x 0 (14 mesh x 0) = 100.0% of Mine Coal Crushed to 1.41 mm.

Quarto Mining Company
Powhattan No. 4 Mine - Pittsburgh No. 8 Seam
Monroe County, Ohio

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

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TABLE E-4. 38.1 mm X 149µ ($1^1/_2$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	8.5	5.33	2.08	.59	8.5	5.33	2.08	.59	100.0	37.25	3.84	2.73
1.30	1.40	34.9	10.64	3.08	1.35	43.4	9.61	3.00	1.21	91.5	40.22	3.95	2.94
1.40	1.60	16.0	22.15	4.90	3.98	59.4	12.94	3.51	1.95	56.6	58.46	4.40	3.94
1.60	1.90	7.9	38.37	5.99	4.49	67.3	15.96	3.80	2.25	40.6	72.77	4.31	3.77
1.90		32.7	82.05	3.91	3.02	100.0	37.25	3.84	2.73	32.7	82.05	3.91	3.52
Head Sample[a]							38.13	2.69	2.65				
Fine[b]							58.79	3.52	1.46				

a) 38.1 mm x 149µ (1½" x 100 mesh) = 98.3% of Raw run of Mine Coal Crushed to 38.1 mm.

b) 149µ x 0 (100 mesh x 0) = 1.7% of Raw Run of Mine Coal Crushed to 38.1 mm.

TABLE E-5. 9.51 mm X 149µ ($^3/_8$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	22.3	4.33	2.45	.39	22.3	4.33	2.45	.39	100.0	37.85	3.75	2.49
1.30	1.40	25.0	13.80	3.42	1.58	47.3	9.18	2.96	1.02	77.7	47.50	4.12	3.09
1.40	1.60	13.0	20.32	5.13	3.71	60.3	11.68	3.43	1.59	52.7	63.60	4.45	3.81
1.60	1.90	6.3	49.75	6.29	5.20	66.6	15.33	3.70	1.94	39.7	77.78	4.23	3.85
1.90		33.4	83.06	3.84	3.59	100.0	37.85	3.75	2.49	33.4	83.06	3.84	3.59
Head Sample[a]							37.33	3.61	2.64				
Fine[b]							47.33	3.53	2.33				

a) 9.51 mm x 149µ ($\frac{3}{8}$" x 100 mesh) = 94.3% of Raw Run of Mine Coal Crushed to 9.51 mm.

b) 149µ x 0 (100 mesh x 0) = 5.7% of Raw Run of Mine Coal Crushed to 9.51 mm.

TABLE E-6. 1.41 mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	14.6	5.76	2.35	.47	14.6	5.76	2.35	.47	100.0	37.03	3.71	2.57
1.30	1.40	28.7	9.54	2.59	1.05	43.3	8.27	2.51	.85	85.4	42.37	3.94	2.93
1.40	1.60	15.4	23.91	4.35	3.37	58.7	12.37	3.04	1.51	56.7	58.99	4.58	3.88
1.60	1.90	8.6	51.77	4.47	4.48	67.3	17.40	3.27	1.89	41.3	72.07	4.56	4.07
1.90		32.7	77.41	4.61	3.96	100.0	37.03	3.71	2.57	32.7	77.41	4.61	3.96
Head Sample[a]							37.18	3.98	2.72				

a) 1.41 mm x 0 (14 mesh x 0) = 100.0% Raw Run of Mine Coal Crushed to 1.41 mm.

National Mines Corporation
Isabella Mine, Pittsburgh Seam
Fayette County, Pennsylvania

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

TABLE E-7. 38.1 mm X 149μ ($1^1/_2$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	15.7	5.64	.94	.30	15.7	5.64	.94	.30	100.0	41.16	1.52	1.06
1.30	1.40	26.3	9.75	1.40	.69	42.0	8.21	1.23	.54	84.3	47.77	1.62	1.20
1.40	1.60	10.5	17.87	2.46	1.41	52.5	10.14	1.47	.72	58.0	65.01	1.72	1.43
1.60	1.90	7.2	34.54	2.24	1.52	59.7	13.09	1.57	.81	47.5	75.43	1.56	1.44
1.90		40.3	82.74	1.44	1.42	100.0	41.16	1.52	1.06	40.3	82.74	1.44	1.42
Head Sample[a]							40.17	1.48	0.95				
Fine[b]							45.06	2.08	1.44				

a) 38.1 mm x 149μ (1-1/2" x 100 mesh) = 99.6% of Raw Run of Mine Coal Crushed to 38.1 mm

b) 149μ x 0 (100 mesh x 0) = 0.4% of Raw Run of Mine Crushed to 38.1 mm

TABLE E-8. 9.51 mm X 149μ ($^3/_8$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	18.6	5.03	.92	.25	18.6	5.03	.92	.25	100.0	40.93	1.52	1.02
1.30	1.40	24.9	10.02	1.27	.33	43.5	7.89	1.12	.30	81.4	49.13	1.65	1.19
1.40	1.60	10.1	17.85	2.04	1.26	53.6	9.76	1.29	.48	56.5	66.37	1.82	1.57
1.60	1.90	6.9	45.92	2.62	1.80	60.5	13.89	1.44	.63	46.4	76.93	1.78	1.64
1.90		39.5	82.35	1.63	1.61	100.0	40.93	1.52	1.02	39.5	82.35	1.63	1.61
Head Sample[a]							41.81	1.58	1.09				
Fine[b]							48.27	1.55	1.23				

a) 9.51 mm x 149μ (3/8" x 100 mesh) = 97.5% of Raw Run of Mine Coal Crushed to 9.51 mm

b) 149μ x 0 (100 mesh x 0) = 2.5% of Raw Run of Mine Coal Crushed to 9.51 mm

TABLE E-9. 1.41 mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	14.7	4.06	.98	.19	14.7	4.06	.98	.19	100.0	40.99	1.64	.99
1.30	1.40	26.0	9.17	1.23	.37	40.7	7.32	1.14	.30	85.3	47.35	1.76	1.13
1.40	1.60	12.7	16.01	2.23	.74	53.4	9.39	1.40	.41	59.3	64.09	1.99	1.47
1.60	1.90	9.6	45.73	1.94	1.60	63.0	14.93	1.48	.59	46.6	77.20	1.92	1.66
1.90		37.0	85.36	1.92	1.68	100.0	40.99	1.64	.99	37.0	85.36	1.92	1.68
Head Sample[a]							40.95	1.57	0.99				

a) 1.41 mm x 0 (14 mesh x 0) = 100.0% of Raw run of Mine Coal Crushed to 1.41 mm

Mathies Coal Company
Mathies Mine - Pittsburgh Seam
Washington County, Pennsylvania

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

TABLE E-10. 38.1 mm X 149µ ($1^1/_2$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	29.3	4.32	1.38	.54	29.3	4.32	1.38	.54	100.0	41.22	1.70	1.2
1.30	1.40	23.5	25.21	2.96	2.35	52.8	13.62	2.08	1.35	70.7	56.51	1.83	1.47
1.40	1.60	7.6	32.06	3.06	2.44	60.4	15.94	2.21	1.48	47.2	72.09	1.27	1.03
1.60	1.90	3.3	49.84	2.83	2.57	63.7	17.60	2.24	1.54	39.6	79.78	.92	.76
1.90		36.3	82.50	.75	.60	100.0	41.22	1.70	1.20	36.3	82.50	.75	.60
Head Sample[a]							41.01	1.59	1.09				
Fine[b]							38.19	2.18	1.54				

a) 38.1 mm x 149µ (1-1/2" x 100 mesh) - 98.1% of Raw Run of Mine Coal Crushed to 38.1 mm.

b) 149µ x 0 (100 mesh x 0) - 1.9% of Raw Run of Mine Coal Crushed to 38.1 mm.

TABLE E-11. 9.51 mm X 149µ ($^3/_8$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	23.5	3.38	1.17	.38	23.5	3.38	1.17	.38	100.0	41.94	1.68	1.19
1.30	1.40	20.5	9.88	2.52	1.71	44.0	6.31	1.80	1.00	76.5	53.79	1.84	1.44
1.40	1.60	9.6	17.33	4.19	3.52	53.6	8.28	2.23	1.45	56.0	69.95	1.59	1.34
1.60	1.90	3.9	26.91	3.20	2.63	57.5	9.54	2.29	1.53	46.4	80.83	1.05	.89
1.90		42.5	85.78	.85	.73	100.0	41.94	1.68	1.19	42.5	85.78	.85	.73
Head Sample[a]							40.82	1.61	1.04				
Fine[b]							41.89	1.79	1.41				

a) 9.51 mm x 149µ (3/8" x 100 mesh) - 94.0% of Raw Run of Mine Coal Crushed to 9.51 mm.

b) 149µ x 0 (100 mesh x 0) - 6.0% of Raw Run of Mine Coal Crushed to 9.51 mm.

TABLt E-12. 1.41 mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	23.0	5.45	1.08	.37	23.0	5.45	1.08	.37	100.0	40.45	1.50	1.05
1.30	1.40	22.3	11.88	1.73	.98	45.3	8.61	1.40	.67	77.0	50.91	1.63	1.28
1.40	1.60	11.4	25.20	2.48	1.95	56.7	11.94	1.62	.93	54.7	66.83	1.58	1.37
1.60	1.90	6.9	39.16	2.12	1.75	63.6	14.69	1.67	1.02	43.3	77.79	1.35	1.22
1.90		36.4	85.11	1.20	1.12	100.0	40.45	1.50	1.05	36.4	85.11	1.20	1.12
Head Sample[a]							40.20	1.56	1.09				

a) 1.41 mm x 0 (14 mesh x 0) - 100.0% of Raw Run of Mine Coal Crushed to 1.41 mm.

Consolidation Coal Co., Mountaineer Coal Co. Div.
Williams Mine, Pittsburgh Seam
Marion County, West Virginia

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

TABLE E-13. 38.1 mm X 149µ (1$^{1}/_{2}$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	55.0	6.18	1.84	.49	55.0	6.18	1.84	.49	100.0	12.29	3.36	2.03
1.30	1.40	31.3	8.52	2.86	1.59	86.3	7.03	2.21	.89	45.0	19.75	5.22	3.91
1.40	1.60	6.5	21.88	6.40	3.78	92.8	8.07	2.50	1.09	13.7	45.40	10.61	9.21
1.60	1.90	1.6	34.38	9.04	8.21	94.4	8.51	2.61	1.21	7.2	66.63	14.41	14.11
1.90		5.6	75.84	15.95	15.79	100.0	12.29	3.36	2.03	5.6	75.84	15.95	15.79
Head Sample[a]							14.01	3.42	2.08				
Fine[b]							21.69	3.81	2.51				

a) 38.1 mm x 149µ (1-1/2"x 100 mesh)= 97.6% of Raw Run of Mine Coal Crushed to 38.1 mm.

b) 149µ x 0 (100 mesh x 0) = 2.4% of Raw Run of Mine Coal Crushed to 38.1 mm.

TABLE E-14. 9.51 mm X 149µ ($^{3}/_{8}$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	47.4	3.63	1.72	.20	47.4	3.63	1.72	.20	100.0	13.03	3.56	2.21
1.30	1.40	38.2	12.97	3.33	1.89	85.6	7.80	2.44	.95	52.6	21.51	5.23	4.01
1.40	1.60	7.1	24.51	7.41	6.50	92.7	9.08	2.82	1.38	14.4	44.15	10.25	9.64
1.60	1.90	1.9	31.46	9.55	8.64	94.6	9.53	2.95	1.52	7.3	63.25	13.02	12.70
1.90		5.4	74.43	14.24	14.13	100.0	13.03	3.56	2.21	5.4	74.43	14.24	14.13
Head Sample[a]							12.85	3.41	1.97				
Fine[b]							17.30	3.56	2.15				

a) 9.51 mm x 149µ (3/8" x 100 mesh) = 92.0% of Raw Run of Mine Coal Crushed to 9.51 mm.

b) 149 x 0 (100 mesh x 0) = 8.0% of Raw Run of Mine Coal Crushed to 9.51 mm.

TABLE E-15. 1.41 mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	50.3	4.28	1.69	.24	50.3	4.28	1.69	.24	100.0	12.80	3.44	2.00
1.30	1.40	34.1	8.72	2.33	.82	84.4	6.07	1.95	.47	49.7	21.42	5.20	3.78
1.40	1.60	5.7	22.20	5.16	3.94	90.1	7.09	2.15	.69	15.6	49.17	11.49	10.26
1.60	1.90	2.3	38.11	8.99	8.20	92.4	7.87	2.32	.88	9.9	64.69	15.13	13.90
1.90		7.6	72.74	16.99	15.63	100.0	12.80	3.44	2.00	7.6	72.74	16.99	15.63
Head Sample[a]							12.59	3.56	2.11				

a) 1.41 mm x 0 (14 mesh x 0) = 100% of Raw Run of Mine Coal Crushed to 1.41 mm.

Consolidation Coal Company
Robinson Run Mine, Pittsburgh Seam
Harrison County, West Virginia

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

TABLE E-16. 38.1 mm X 149µ ($1^1/_2$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	43.7	4.13	2.24	.37	43.7	4.13	2.24	.37	100.0	12.88	4.17	2.55
1.30	1.40	39.8	8.52	3.38	1.62	83.5	6.22	2.78	.97	56.3	19.67	5.67	4.23
1.40	1.60	6.9	18.64	6.69	5.48	90.4	7.17	3.08	1.31	16.5	46.56	11.18	10.54
1.60	1.90	1.8	33.24	9.06	8.33	92.2	7.68	3.20	1.45	9.6	66.63	14.41	14.17
1.90		7.8	74.33	15.65	15.52	100.0	12.88	4.17	2.55	7.8	74.33	15.65	15.52
Head Sample[a]							13.36	3.95	2.61				
Fine[b]							17.21	4.16	2.39				

a) 38.1 mm x 149µ (1-1/2" x 100 mesh) = 97.0% of Raw Run of Mine Coal Crushed to 38.1 mm.

b) 149µ x 0 (100 mesh x 0) = 3.0% of Raw Run of Mine Coal Crushed to 38.1 mm.

TABLE E-17. 9.51 mm X 149µ ($^3/_8$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	53.7	4.14	2.19	.46	53.7	4.14	2.19	.46	100.0	13.22	4.25	2.65
1.30	1.40	28.8	9.08	3.38	1.40	82.5	5.86	2.61	.79	46.3	23.76	6.63	5.18
1.40	1.60	6.4	16.02	6.40	5.20	88.9	6.60	2.88	1.11	17.5	47.91	11.98	11.40
1.60	1.90	2.1	31.74	9.74	8.86	91.0	7.18	3.04	1.28	11.1	66.30	15.20	14.97
1.90		9.0	74.37	16.47	16.40	100.0	13.22	4.25	2.65	9.0	74.37	16.47	16.40
Head Sample[a]							13.17	4.37	2.77				
Fine[b]							17.62	4.11	2.51				

a) 9.51 mm x 149µ (3/8" x 100 mesh) = 95.6% of Raw Run of Mine Coal Crushed to 9.51 mm.

b) 149µ x 0 (100 mesh x 0) = 4.4% of Raw Run of Mine Coal Crushed to 9.51 mm.

TABLE E-18. 1.41 mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	54.1	4.62	2.25	.41	54.1	4.62	2.25	.41	100.0	13.04	4.40	2.73
1.30	1.40	27.5	9.43	3.05	1.31	81.6	6.24	2.52	.71	45.9	22.96	6.93	5.46
1.40	1.60	6.9	18.70	6.28	4.71	88.5	7.21	2.81	1.02	18.4	43.18	12.73	11.67
1.60	1.90	2.4	35.20	10.30	9.23	90.9	7.95	3.01	1.24	11.5	57.87	16.60	15.85
1.90		9.1	63.85	18.26	17.60	100.0	13.04	4.40	2.73	9.1	63.85	18.26	17.60
Head Sample[a]							13.00	4.18	2.63				

a) 1.41 mm x 0 (14 mesh x 0) = 100% of Raw Run of Mine Coal Crushed to 1.41 mm.

Consolidation Coal Company
Shoemaker Mine, Pittsburgh Seam
Marshall Co., West Virginia

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

TABLE E-19. 38.1 mm X 149μ ($1^1/_2$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	32.4	4.28	2.46	.53	32.4	4.28	2.46	.53	100.0	32.44	4.18	2.89
1.30	1.40	24.8	14.09	3.57	1.83	57.2	8.53	2.94	1.09	67.6	45.94	5.00	4.02
1.40	1.60	10.2	18.49	5.86	4.25	67.4	10.04	3.38	1.57	42.8	64.39	5.83	5.29
1.60	1.90	3.2	30.74	6.85	5.64	70.6	10.98	3.54	1.76	32.6	78.75	5.82	5.61
1.90		29.4	83.98	5.71	5.61	100.0	32.44	4.18	2.89	29.4	83.98	5.71	5.61
Head Sample[a]							32.55	4.03	2.73				
Fine[b]							32.62	3.38	2.53				

a) 38.1 mm x 149μ (1-1/2" x 100 mesh) = 97.8% of Raw Run of Mine Coal Crushed to 38.1 mm

b) 149μ x 0 (100 mesh x 0) = 2.2% of Raw Run of Mine Coal Crushed to 38.1 mm

TABLE E-20. 9.51 mm X 149μ ($^3/_8$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	26.3	3.73	2.40	.54	26.3	3.73	2.40	.54	100.0	32.29	4.01	2.87
1.30	1.40	28.6	9.08	3.14	1.65	54.9	6.52	2.79	1.12	73.7	42.49	4.59	3.70
1.40	1.60	12.2	20.52	5.59	4.04	67.1	9.06	3.30	1.65	45.1	63.67	5.50	5.00
1.60	1.90	3.0	29.31	7.29	6.26	70.1	9.93	3.47	1.85	32.9	79.68	5.47	5.35
1.90		29.9	84.73	5.29	5.26	100.0	32.29	4.01	2.87	29.9	84.73	5.29	5.26
Head Sample[a]							32.96	3.74	2.53				
Fine[b]							36.35	3.75	2.51				

a) 9.51 mm x 149μ (3/8" x 100 mesh) = 96.5% of Raw Run of Mine Coal Crushed to 9.51 mm

b) 149μ x 0 (100 mesh x 0) = 3.5% of Raw Run of Mine Coal Crushed to 9.51 mm

TABLE E-21. 1.41 mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	23.3	3.49	2.34	.45	23.3	3.49	2.34	.45	100.0	32.51	4.04	2.89
1.30	1.40	28.7	7.50	2.93	1.47	52.0	5.70	2.67	1.01	76.7	41.32	4.56	3.64
1.40	1.60	12.8	20.45	5.47	4.00	64.8	8.62	3.22	1.60	48.0	61.55	5.54	4.93
1.60	1.90	7.5	43.45	7.08	6.15	72.3	12.23	3.62	2.07	35.2	76.49	5.56	5.27
1.90		27.7	85.44	5.15	5.03	100.0	32.51	4.04	2.89	27.7	85.44	5.15	5.03
Head Sample[a]							32.46	3.71	2.60				

a) 1.41 mm x 0 (14 mesh x 0) = 100% of Raw Run of Mine Coal Crushed to 1.41 mm

Eastern Associated Coal Corp.
Delmont Mine, Upper Freeport Seam
Westmoreland County, Pennsylvania

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

TABLE E-22. 38.1 mm X 149μ ($1^1/_2$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	37.6	4.85	1.33	.79	37.6	4.85	1.33	.79	100.0	27.29	4.50	4.10
1.30	1.40	18.9	11.82	3.34	2.95	56.5	7.18	2.00	1.51	62.4	40.81	6.41	6.10
1.40	1.60	13.1	19.08	6.15	5.60	69.6	9.42	2.78	2.28	43.5	53.41	7.74	7.47
1.60	1.90	5.3	27.99	7.66	7.39	74.9	10.74	3.13	2.[illegible]	30.4	68.20	8.43	8.27
1.90		25.1	76.69	8.59	8.46	100.0	27.29	4.50	4.10	25.1	76.69	8.59	8.46
Head Sample[a]							26.80	4.37	4.01				
Fine[b]							16.85	3.63	2.14				

a) 38.1 mm x 149μ (1-1/2" x 100 mesh) = 97.9% of Raw Run of Mine Coal Crushed to 38.1 mm.

b) 149μ x 0 (100 mesh x 0) = 2.1% of Raw Run of Mine Coal Crushed to 38.1 mm.

TABLE E-23. 9.51 mm X 149μ ($^3/_8$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	39.1	4.23	1.09	.62	39.1	4.23	1.09	.62	100.0	26.67	4.67	4.31
1.30	1.40	19.5	14.83	3.44	3.06	58.6	7.76	1.87	1.43	60.9	41.07	6.98	6.68
1.40	1.60	11.6	22.62	5.68	5.15	70.2	10.21	2.50	2.05	41.4	53.44	8.64	8.38
1.60	1.90	5.0	31.51	7.34	7.06	75.2	11.63	2.82	2.38	29.8	65.43	9.80	9.64
1.90		24.8	72.27	10.29	10.16	100.0	26.67	4.67	4.31	24.8	72.27	10.29	10.16
Head Sample[a]							26.78	4.59	4.20				
Fine[b]							21.53	3.31	1.95				

a) 9.51 mm x 149μ (3/8" x 100 mesh) = 93.5% of Raw Run of Mine Coal Crushed to 9.51 mm.

b) 149μ x 0 (100 mesh x 0) = 6.5% of Raw Run of Mine Coal Crushed to 9.51 mm.

TABLE E-24. 1.41 mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	40.4	4.48	1.14	.41	40.4	4.48	1.14	.41	100.0	27.15	4.55	4.00
1.30	1.40	20.1	11.22	2.16	1.41	60.5	6.72	1.48	.74	59.6	42.52	6.86	6.43
1.40	1.60	8.1	23.69	4.54	3.66	68.6	8.72	1.84	1.09	39.5	58.44	9.25	8.98
1.60	1.90	3.9	37.89	7.15	6.62	72.5	10.29	2.13	1.38	31.4	67.40	10.47	10.35
1.90		27.5	71.59	10.94	10.88	100.0	27.15	4.55	4.00	27.5	71.59	10.94	10.88
Head Sample[a]							27.55	4.38	4.18				

a) 1.41 mm x 0 (14 mesh x 0) = 100% of Raw Run of Mine Coal Crushed to 1.41 mm.

Tunnelton Mining Co.
Marion Mine - Upper Freeport Seam
Indiana County, Pennsylvania

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

TABLE E-25. 38.1 mm X 149μ ($1^{1}/_{2}$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	34.5	3.81	.93	.24	34.5	3.81	.93	.24	100.0	26.61	1.51	1.10
1.30	1.40	26.1	12.46	1.24	.81	60.6	7.54	1.06	.49	65.5	38.62	1.81	1.55
1.40	1.60	9.1	17.77	1.48	1.28	69.7	8.87	1.12	.59	39.4	55.96	2.19	2.04
1.60	1.90	7.0	38.62	1.86	1.50	76.7	11.59	1.19	.67	30.3	67.43	2.40	2.27
1.90		23.3	76.08	2.56	2.50	100.0	26.61	1.51	1.10	23.3	76.08	2.56	2.50
Head Sample[a]							25.75	1.37	0.80				
Fine[b]							20.53	1.51	0.83				

a) 38.1 mm x 149μ (1-1/2" x 100 mesh) = 96.3% of Raw Run of Mine Coal Crushed to 38.1 mm.

b) 149μ x 0 (100 mesh x 0) = 3.7% of Raw Run of Mine Coal Crushed to 38.1 mm.

TABLE E-26. 9.51 mm X 149μ ($^{3}/_{8}$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	37.8	3.15	.82	.21	37.8	3.15	.82	.21	100.0	26.14	1.50	1.01
1.30	1.40	23.4	12.84	1.12	.52	61.2	6.85	.93	.33	62.2	40.10	1.91	1.50
1.40	1.60	7.8	19.53	1.79	1.34	69.0	8.29	1.03	.44	38.8	56.55	2.39	2.09
1.60	1.90	6.6	34.73	2.02	1.63	75.6	10.60	1.12	.55	31.0	65.86	2.54	2.28
1.90		24.4	74.28	2.68	2.45	100.0	26.14	1.50	1.01	24.4	74.28	2.68	2.45
Head Sample[a]							26.01	1.50	0.97				
Fine[b]							25.13	1.57	0.84				

a) 9.51 mm x 149μ (3/8" x 100 mesh) = 94.6% of Raw Run of Mine Coal Crushed to 9.51 mm.

b) 149μ x 0 (100 mesh x 0) = 5.4% of Raw Run of Mine Coal Crushed to 9.51 mm.

TABLE E-27. 1.41 mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	35.8	3.72	.88	.19	35.8	3.72	.88	.19	100.0	25.94	1.54	1.04
1.30	1.40	22.3	9.24	1.14	.57	58.1	5.84	.98	.34	64.2	38.33	1.91	1.52
1.40	1.60	12.6	17.86	1.66	1.25	70.7	7.98	1.10	.50	41.9	53.81	2.32	2.02
1.60	1.90	5.6	36.08	1.98	1.67	76.3	10.04	1.17	.58	29.3	69.27	2.61	2.36
1.90		23.7	77.11	2.76	2.52	100.0	25.94	1.54	1.04	23.7	77.11	2.76	2.52
Head Sample[a]							25.42	1.50	0.75				

a) 1.41 mm x 0 (14 mesh x 0) = 100.0% of Mine Coal Crushed to 1.41 mm.

Buckeye Coal Mining Company
Lucas Mine - Middle Kittanning Seam
Columbiana County, Ohio

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

TABLE E-28. 38.1 mm X 149µ ($1^1/_2$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	68.5	5.19	.90	.54	68.5	5.19	.90	.54	100.0	9.04	1.75	1.40
1.30	1.40	23.3	10.22	1.81	1.43	91.8	6.47	1.13	.77	31.5	17.41	3.61	3.27
1.40	1.60	4.2	21.06	3.71	3.62	96.0	7.11	1.24	.89	8.2	37.83	8.73	8.51
1.60	1.90	1.5	38.33	6.24	6.20	97.5	7.59	1.32	.97	4.0	55.43	14.00	13.64
1.90		2.5	65.69	18.66	18.11	100.0	9.04	1.75	1.40	2.5	65.69	18.66	18.11
Head Sample[a]							8.79	1.76	1.33				
Fine[b]							17.33	2.51	1.74				

a) 38.1 mm x 149µ (1-1/2" x 100 mesh) = 98.5% of Raw Run of Mine Coal Crushed to 38.1 mm.

b) 149µ x 0 (100 mesh x 0) = 1.5% of Raw Run of Mine Coal Crushed to 38.1 mm.

TABLE E-29. 9.51 mm X 149µ ($^3/_8$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	70.0	3.32	.69	.13	70.0	3.32	.69	.13	100.0	9.05	1.85	1.31
1.30	1.40	20.2	11.76	1.76	1.31	90.2	5.21	.93	.39	30.0	22.41	4.56	4.07
1.40	1.60	3.9	26.92	3.61	3.05	94.1	6.11	1.04	.50	9.8	44.37	10.34	9.77
1.60	1.90	1.4	33.08	5.59	5.27	95.5	6.51	1.11	.57	5.9	55.90	14.78	14.22
1.90		4.5	63.00	17.64	17.00	100.0	9.05	1.85	1.31	4.5	63.00	17.64	17.00
Head Sample[a]							8.88	1.92	1.41				
Fine[b]							10.34	1.50	0.95				

a) 9.51 mm x 149µ (3/8" x 100 mesh) = 95.2% of Raw Run of Mine Coal Crushed to 9.51 mm.

b) 149µ x 0 (100 mesh x 0) = 4.8% of Raw Run of Mine Coal Crushed to 9.51 mm.

TABLE E-30. 1.41 mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	62.7	3.12	.53	.17	62.7	3.12	.53	.17	100.0	9.16	1.75	1.40
1.30	1.40	23.3	7.71	.69	.35	86.0	4.36	.57	.22	37.3	19.32	3.80	3.47
1.40	1.60	6.2	14.37	1.26	.93	92.2	5.04	.62	.27	14.0	38.64	8.96	8.65
1.60	1.90	2.2	37.65	2.81	2.64	94.4	5.80	.67	.32	7.8	57.92	15.09	14.79
1.90		5.6	65.89	19.91	19.57	100.0	9.16	1.75	1.40	5.6	65.89	19.91	19.57
Head Sample[a]							9.12	1.81	1.43				

a) 1.41 mm x 0 (14 mesh x 0) = 100.0% of Raw Run of Mine Coal Crushed to 1.41 mm.

Island Creek Coal Company
Bird No. 3 Mine, Lower Kittanning Seam
Somerset County, Pennsylvania

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

TABLE E-31. 38.1 mm X 149μ ($1^1/_2$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	24.5	3.51	.84	.38	24.5	3.51	.84	.38	100.0	27.76	2.93	2.55
1.30	1.40	34.1	7.75	1.82	1.41	58.6	5.98	1.41	.98	75.5	35.63	3.60	3.26
1.40	1.60	9.7	17.55	2.57	2.12	68.3	7.62	1.57	1.14	41.4	58.60	5.07	4.78
1.60	1.90	5.4	38.67	4.43	4.04	73.7	9.90	1.78	1.35	31.7	71.16	5.84	5.60
1.90		26.3	77.83	6.13	5.92	100.0	27.76	2.93	2.55	26.3	77.83	6.13	5.92
Head Sample[a]							27.09	2.97	2.55				
Fine[b]							16.69	2.46	1.78				

a) 38.1 mm x 149μ (1-1/2" x 100 mesh) = 97.4% of Raw Run of Mine Coal Crushed to 38.1 mm.

b) 149μ x 0 (100 mesh x 0) = 2.6% of Raw Run of Mine Coal Crushed to 38.1 mm.

TABLE E-32. 9.51 mm X 149μ ($^3/_8$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	20.8	2.74	.74	.26	20.8	2.74	.74	.26	100.0	26.94	2.89	2.46
1.30	1.40	38.8	5.78	1.13	.63	59.6	4.72	.99	.50	79.2	33.30	3.45	3.03
1.40	1.60	9.6	15.24	2.26	1.30	69.2	6.18	1.17	.61	40.4	59.73	5.69	5.34
1.60	1.90	3.5	30.32	3.52	2.63	72.7	7.34	1.28	.71	30.8	73.59	6.76	6.60
1.90		27.3	79.14	7.17	7.11	100.0	26.94	2.89	2.46	27.3	79.14	7.17	7.11
Head Sample[a]							26.04	3.01	2.57				
Fine[b]							20.24	2.49	1.89				

a) 9.51 mm x 149μ (3/8" x 100 mesh) = 96.1% of Raw Run of Mine Coal Crushed to 9.51 mm.

b) 149μ X 0 (100 mesh x 0) = 3.9% of Raw Run of Mine Coal Crushed to 9.51 mm.

TABLE E-33. 1.41 mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	24.2	3.17	1.06	.26	24.2	3.17	1.06	.26	100.0	27.14	2.89	2.41
1.30	1.40	35.7	7.22	1.33	.77	59.9	5.58	1.22	.56	75.8	34.79	3.47	3.10
1.40	1.60	8.6	18.87	2.61	2.06	68.5	7.25	1.40	.75	40.1	59.34	5.37	5.17
1.60	1.90	3.4	39.97	4.06	3.74	71.9	8.80	1.52	.89	31.5	70.39	6.13	6.01
1.90		28.1	74.07	6.38	6.29	100.0	27.14	2.89	2.41	28.1	74.07	6.38	6.29
Head Sample[a]							26.98	3.03	2.49				

a) 1.41 mm x 0 (14 mesh x 0) = 100% of Raw Run of Mine Coal Crushed to 1.41 mm.

American Electric Power Company
Martinka Mine, Lower Kittanning Seam
Logan County, West Virginia

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

TABLE E-34. 38.1 mm X 149μ ($1^1/_2$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	12.0	4.01	.77	.13	12.0	4.01	.77	.13	100.0	43.78	1.82	1.53
1.30	1.40	23.0	14.11	1.14	.61	35.0	10.65	1.01	.45	88.0	49.21	1.96	1.72
1.40	1.60	16.1	28.84	1.86	1.57	51.1	16.38	1.28	.80	65.0	61.63	2.25	2.11
1.60	1.90	11.5	41.56	1.96	1.73	62.6	21.01	1.40	.97	48.9	72.42	2.38	2.29
1.90		37.4	81.91	2.51	2.46	100.0	43.78	1.82	1.53	37.4	81.91	2.51	2.46
Head Sample[a]							44.86	1.78	1.64				
Fine[b]							49.26	2.20	2.02				

a) 38.1 mm x 149μ (1½" x 100 mesh) = 96.5% of Raw Run of Mine Coal Crushed to 38.1 mm

b) 149μ x 0 (100 mesh x 0) = 3.5% of Raw Run of Mine Coal Crushed to 38.1 mm

TABLE E-35. 9.51 mm X 149μ ($^3/_8$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	8.2	5.26	.78	.19	8.2	5.26	.78	.19	100.0	45.68	1.91	1.64
1.30	1.40	21.8	15.04	1.12	.66	30.0	12.37	1.03	.53	91.8	49.29	2.01	1.77
1.40	1.60	18.5	25.92	1.55	1.23	48.5	17.54	1.23	.80	70.0	59.95	2.29	2.12
1.60	1.90	13.0	42.71	1.60	1.36	61.5	22.86	1.31	.92	51.5	72.18	2.55	2.44
1.90		38.5	82.13	2.87	2.80	100.0	45.68	1.91	1.64	38.5	82.13	2.87	2.80
Head Sample[a]							46.06	1.88	1.63				
Fine[b]							48.38	2.11	1.80				

a) 9.51 mm x 149μ (3/8" x 100 mesh) = 98% of Raw Run of Mine Coal Crushed to 9.51 mm

b) 149μ x 0 (100 mesh x 0) = 2% of Raw Run of Mine Coal Crushed to 9.51 mm

TABLE E-36. 1.41 mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	15.8	6.25	.68	.10	15.8	6.25	.68	.10	100.0	46.58	1.98	1.73
1.30	1.40	18.4	15.32	.72	.32	34.2	11.15	.70	.22	84.2	54.14	2.23	2.04
1.40	1.60	10.4	26.40	.90	.58	44.6	14.60	.75	.30	65.8	65.00	2.65	2.52
1.60	1.90	11.9	47.16	1.20	1.06	56.5	21.53	.84	.46	55.4	72.25	2.97	2.88
1.90		43.5	79.11	3.46	3.38	100.0	46.58	1.98	1.73	43.5	79.11	3.46	3.38
Head Sample[a]							46.18	1.82	1.74				

a) 1.41 mm x 0 (14 mesh x 0) = 100% of Raw Run of Mine Coal Crushed to 1.41 mm

American Electric Power Company
Meigs Mine - Clarion 4A Seam
Meigs County, Ohio

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

TABLE E-37. 38.1 mm X 149µ ($1^1/_2$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	37.1	3.50	1.87	.41	37.1	3.50	1.87	.41	100.0	25.46	3.52	2.14
1.30	1.40	29.4	14.76	3.17	1.56	66.5	8.48	2.44	.92	62.9	38.42	4.49	3.16
1.40	1.60	8.7	25.55	4.33	3.18	75.2	10.45	2.66	1.18	33.5	59.18	5.65	4.57
1.60	1.90	4.4	39.55	3.89	2.95	79.6	12.06	2.73	1.29	24.8	70.79	6.11	5.06
1.90		20.4	77.75	6.59	5.51	100.0	25.46	3.52	2.14	20.4	77.75	6.59	5.51
Head Sample[a]							24.62	3.70	1.91				
Fine[b]							24.60	3.27	1.86				

a) 38.1 mm x 149µ (1-1/2"x100 mesh) = 96.0% of Raw Run of Mine Coal Crushed to 38.1 mm.

b) 149µ x 0 (100 mesh x 0) = 4.0% of Raw Run of the Mine Coal Crushed to 38.1 mm.

TABLE E-38. 9.51 mm X 149µ ($^3/_8$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	34.0	3.71	2.10	.39	34.0	3.71	2.10	.39	100.0	24.85	3.44	2.18
1.30	1.40	32.8	13.13	2.97	1.45	66.8	8.34	2.53	.91	66.0	35.74	4.13	3.10
1.40	1.60	10.0	38.33	4.56	3.36	76.8	10.94	2.79	1.23	33.2	58.07	5.28	4.74
1.60	1.90	4.0	40.65	4.56	3.77	80.8	12.41	2.88	1.36	23.2	70.89	5.59	5.33
1.90		19.2	77.19	5.80	5.66	100.0	24.85	3.44	2.18	19.2	77.19	5.80	5.66
Head Sample[a]							25.23	3.63	2.02				
Fine[b]							30.32	3.29	2.01				

a) 9.51 mm x 149µ (3/8" x 100 mesh) = 93.1% of Raw Run of Mine Coal Crushed to 9.51 mm.

b) 149µ x 0 (100 mesh x 0) = 6.9% of Raw Run of Mine Coal Crushed to 9.51 mm.

TABLE E-39. 1.41 mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	22.2	3.95	2.05	.23	22.2	3.95	2.05	.23	100.0	24.07	3.34	1.78
1.30	1.40	38.6	11.98	2.66	.79	60.8	9.05	2.44	.58	77.8	29.82	3.71	2.22
1.40	1.60	14.9	18.99	3.63	1.90	75.7	11.00	2.67	.84	39.2	47.38	4.78	3.63
1.60	1.90	7.4	45.70	4.41	3.39	83.1	14.10	2.83	1.07	24.3	64.79	5.43	4.68
1.90		16.9	73.11	5.87	5.25	100.0	24.07	3.34	1.78	16.9	73.11	5.87	5.25
Head Sample[a]							24.52	3.38	1.75				

a) 1.41 mm x 0 (14 mesh x 0) = 100.0% of Raw Run of Mine Coal Crushed to 1.41 mm.

Royal Dean Coal Co., Inc.
Dean Mine, Dean Seam
Scott County, Tennessee

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

TABLE E-40. 38.1 mm X 149μ ($1^1/_2$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	32.7	4.03	2.44	.48	32.7	4.03	2.44	.48	100.0	20.09	4.34	2.88
1.30	1.40	31.6	8.13	2.88	1.15	64.3	6.04	2.66	.81	67.3	27.89	5.27	4.05
1.40	1.60	13.0	18.53	3.74	2.23	77.3	8.14	2.84	1.05	35.7	45.38	7.38	6.61
1.60	1.90	6.8	36.56	5.85	4.93	84.1	10.44	3.08	1.36	22.7	60.76	9.47	9.13
1.90		15.9	71.11	11.02	10.92	100.0	20.09	4.34	2.88	15.9	71.11	11.02	10.92
Head Sample[a]							19.12	4.37	2.75				
Fine[b]							28.97	3.96	2.51				

a) 38.1 mm x 149μ (1-1/2" x 100 mesh) = 99.0% of Raw Run of Mine Coal Crushed to 38.1 mm.

b) 149μ x 0 (100 mesh x 0) = 1.0% of Raw Run of Mine Coal Crushed to 38.1 mm.

TABLE E-41. 9.51 mm X 149μ ($^3/_8$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	35.8	4.21	2.30	.46	35.8	4.21	2.30	.46	100.0	19.36	4.12	2.71
1.30	1.40	32.3	13.45	3.20	1.60	68.1	8.59	2.73	1.00	64.2	27.80	5.14	3.96
1.40	1.60	15.0	22.62	4.21	3.01	83.1	11.12	2.99	1.36	31.9	42.34	7.11	6.35
1.60	1.90	5.7	40.88	6.21	5.40	88.8	13.03	3.20	1.62	16.9	59.83	9.68	9.32
1.90		11.2	69.48	11.44	11.32	100.0	19.36	4.12	2.71	11.2	69.48	11.44	11.32
Head Sample[a]							19.03	4.23	2.68				
Fine[b]							18.10	2.86	1.99				

a) 9.51 mm x 149μ (3/8" x 100 mesh) = 95.3% of Raw Run of Mine Coal Crushed to 9.51 mm.

b) 149μ x 0 (100 mesh x 0) = 4.7% of Raw Run of Mine Coal Crushed to 9.51 mm.

TABLE E-42. 1.41 mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	42.9	8.91	2.67	.92	42.9	8.91	2.67	.92	100.0	18.95	4.20	2.57
1.30	1.40	25.3	9.99	3.09	1.25	68.2	9.31	2.83	1.04	57.1	26.50	5.35	3.80
1.40	1.60	14.9	22.58	3.71	1.93	83.1	11.69	2.98	1.20	31.8	39.64	7.14	5.83
1.60	1.90	5.0	28.68	4.13	2.20	88.1	12.65	3.05	1.26	16.9	54.68	10.16	9.27
1.90		11.9	65.60	12.70	12.24	100.0	18.95	4.20	2.57	11.9	65.60	12.70	12.24
Head Sample[a]							19.90	4.09	2.60				

a) 1.41 mm x 0 (14 mesh x 0) = 100.0% of Raw Run of Mine Coal Crushed to 1.41 mm.

Eastern Associated Coal Corp.
Kopperston No. 2, Campbell Creek Seam
Wyoming County, West Virginia

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

TABLE E-43. 38.1 mm X 149μ (1¹/₂" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
Sink	Float	%Wt.	%Ash	%Sulfur Total	%Sulfur Pyritic	%Wt.	%Ash	%Sulfur Total	%Sulfur Pyritic	%Wt.	%Ash	%Sulfur Total	%Sulfur Pyritic
	1.30	40.2	3.94	.79	.24	40.2	3.94	.79	.24	100.0	28.43	.93	.51
1.30	1.40	20.5	7.11	.88	.31	60.7	5.01	.82	.26	59.8	44.90	1.02	.70
1.40	1.60	7.3	15.00	1.23	.63	68.0	6.08	.86	.30	39.3	64.61	1.09	.90
1.60	1.90	3.5	36.17	1.74	1.06	71.5	7.46	.91	.34	32.0	75.93	1.06	.96
1.90		28.5	81.06	.98	.95	100.0	28.43	.93	.51	28.5	81.06	.98	.95
Head Sample[a]							28.15	.95	.49				
Fine[b]							28.61	.94	.36				

a) 38.1 mm x 149μ (1-1/2" x 100 mesh) = 99.5% of Raw Run of Mine Coal Crushed to 38.1 mm

b) 149μ x 0 (100 mesh x 0) = .5% of Raw Run of Mine Coal Crushed to 38.1 mm

TABLE E-44. 9.51 mm X 149μ (³/₈" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
Sink	Float	%Wt.	%Ash	%Sulfur Total	%Sulfur Pyritic	%Wt.	%Ash	%Sulfur Total	%Sulfur Pyritic	%Wt.	%Ash	%Sulfur Total	%Sulfur Pyritic
	1.30	47.7	3.06	.95	.27	47.7	3.06	.95	.27	100.0	28.05	1.02	.53
1.30	1.40	19.5	18.22	1.04	.54	67.2	7.46	.98	.35	52.3	50.84	1.09	.76
1.40	1.60	6.0	29.01	1.53	1.14	73.2	9.23	1.02	.41	32.8	70.23	1.12	.89
1.60	1.90	2.1	37.70	2.29	1.77	75.3	10.02	1.06	.45	26.8	79.46	1.03	.84
1.90		24.7	83.01	.92	.76	100.0	28.05	1.02	.53	24.7	83.01	.92	.76
Head Sample[a]							27.98	.97	.51				
Fine[b]							28.89	.91	.39				

a) 9.51 mm x 149μ (3/8" x 100 mesh) = 97.1% of Raw Run of Mine Coal Crushed to 9.51 mm

b) 149μ x 0 (100 mesh x 0) = 2.9% of Raw Run of Mine Coal Crushed to 9.51 mm

TABLE E-45. 1.41mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
Sink	Float	%Wt.	%Ash	%Sulfur Total	%Sulfur Pyritic	%Wt.	%Ash	%Sulfur Total	%Sulfur Pyritic	%Wt.	%Ash	%Sulfur Total	%Sulfur Pyritic
	1.30	22.9	3.08	.63	.23	22.9	3.08	.63	.23	100.0	27.23	.89	.50
1.30	1.40	32.7	8.14	.75	.21	55.6	6.06	.70	.22	77.1	34.40	.97	.58
1.40	1.60	15.7	19.98	1.09	.52	71.3	9.12	.79	.28	44.4	53.74	1.13	.86
1.60	1.90	5.0	42.46	1.48	1.17	76.3	11.31	.83	.34	28.7	72.20	1.15	1.05
1.90		23.7	78.48	1.08	1.02	100.0	27.23	.89	.50	23.7	78.48	1.08	1.02
Head Sample[a]							27.85	.90	.48				

a) 1.41 mm x 0 (14 mesh x 0) = 100% of Raw Run of Mine Coal Crushed to 1.41 mm

Eastern Associated Coal Corp.
Harris Mines #1 & #2, Eagle & #2 Gas Seam
Boone County, West Virginia

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

TABLE E-46. 38.1 mm X 149μ ($1^1/_2$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	44.9	2.91	.93	.15	44.9	2.91	.93	.15	100.0	21.16	1.03	.47
1.30	1.40	18.6	14.35	1.17	.64	63.5	5.26	1.00	.29	55.1	36.03	1.12	.73
1.40	1.60	12.4	23.18	1.45	.84	75.9	9.03	1.07	.38	36.5	47.07	1.09	.77
1.60	1.90	9.1	47.45	1.13	.72	85.0	13.14	1.08	.42	24.1	59.36	.91	.74
1.90		15.0	66.59	.77	.75	100.0	21.16	1.03	.47	15.0	66.59	.77	.75
Head Sample[a]							20.95	1.10	.55				
Fine[b]							14.36	1.07	.40				

a) 38.1 mm x 149μ (1-1/2" x 100 mesh) = 98.8% of Raw Run of Mine Coal Crushed to 38.1 mm.

b) 149μ x 0 (100 mesh x 0) = 1.2% of Raw Run of Mine Coal Crushed to 38.1 mm.

TABLE E-47. 9.51 mm X 149μ ($^3/_8$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	44.1	3.75	.84	.23	44.1	3.75	.84	.23	100.0	20.14	1.05	.53
1.30	1.40	25.5	15.85	1.28	.69	69.6	8.18	1.00	.40	55.9	33.06	1.22	.77
1.40	1.60	8.9	27.93	1.38	.72	78.5	10.42	1.04	.43	30.4	47.50	1.17	.63
1.60	1.90	8.4	35.91	1.49	1.14	86.9	12.89	1.09	.50	21.5	55.60	1.09	.88
1.90		13.1	68.23	.83	.71	100.1	20.14	1.05	.53	13.1	68.23	.83	.71
Head Sample[a]							19.85	1.01	.50				
Fine[b]							26.95	1.06	.56				

a) 9.51 mm x 149μ (3/8" x 100 mesh) = 98.4% of Raw Run of Mine Coal Crushed to 9.51 mm.

b) 149μ x 0 (100 mesh x 0) = 1.6% of Raw Run of Mine Coal Crushed to 9.51 mm.

TABLE E-48. 1.41 mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	34.7	3.93	.72	.19	34.7	3.93	.72	.19	100.0	19.19	1.05	.51
1.30	1.40	28.7	8.27	.93	.30	63.4	5.89	.82	.24	65.3	27.30	1.22	.68
1.40	1.60	12.6	21.65	1.16	.62	76.0	8.51	.87	.30	36.6	42.21	1.45	.98
1.60	1.90	12.8	40.62	1.20	.71	88.8	13.14	.92	.36	24.0	53.01	1.61	1.17
1.90		11.2	67.17	2.07	1.69	100.0	19.19	1.05	.51	11.2	67.17	2.07	1.69
Head Sample[a]							19.47	1.03	.46				

a) 1.41 mm x 0 (14 mesh x 0) = 100.0% of Raw Run of Mine Coal Crushed to 1.41 mm.

Republic Steel Corporation
North River Mine, Corona Seam
Jefferson County, Alabama

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

TABLE E-49. 38.1 mm X 149µ (1½" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	10.8	5.16	1.59	.88	10.8	5.16	1.59	.88	100.0	57.71	1.67	1.03
1.30	1.40	21.5	20.48	2.22	1.40	32.3	15.36	2.01	1.23	89.2	64.07	1.68	1.05
1.40	1.60	10.3	31.10	2.97	2.66	42.6	19.16	2.24	1.57	67.7	77.91	1.50	.94
1.60	1.90	4.6	42.36	3.08	2.77	47.2	21.42	2.32	1.69	57.4	86.31	1.24	.63
1.90		52.8	90.14	1.08	.44	100.0	57.71	1.67	1.03	52.8	90.14	1.08	.44
Head Sample[a]							55.05	1.62	1.01				
Fine[b]							52.97	1.78	.88				

a) 38.1 mm x 149µ (1½" x 100 mesh) = 98.0% of Raw Run of Mine Coal Crushed to 38.1 mm

b) 149µ x 0 (100 mesh x 0) = 2.0% of Raw Run of Mine Coal Crushed to 38.1 mm

TABLE E-50. 9.51 mm X 149µ (3/8" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	14.2	4.40	1.37	.39	14.2	4.40	1.37	.39	100.0	54.84	1.70	1.12
1.30	1.40	19.6	21.51	2.24	1.32	33.8	14.32	1.87	.93	85.8	63.19	1.76	1.24
1.40	1.60	10.4	28.48	2.73	1.84	44.2	17.65	2.08	1.14	66.2	75.53	1.62	1.22
1.60	1.90	5.9	44.27	2.9	2.18	50.1	20.79	2.18	1.27	55.8	84.30	1.41	1.11
1.90		49.9	89.03	1.23	.98	100.0	54.84	1.70	1.12	49.9	89.03	1.23	.98
Head Sample[a]							53.65	1.70	1.08				
Fine[b]							57.87	1.56	.95				

a) 9.51 mm x 149µ (3/8" x 100 mesh) = 92.1% of Raw Run of Mine Coal Crushed to 9.51 mm

b) 149µ x 0 (100 mesh x 0) = 7.9% of Raw Run of Mine Coal Crushed to 9.51 mm

TABLE E-51. 1.41 mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	21.3	5.11	1.59	.44	21.3	5.11	1.59	.44	100.0	46.34	1.81	1.09
1.30	1.40	16.2	9.68	2.31	1.08	37.5	7.08	1.90	.72	78.7	57.50	1.87	1.27
1.40	1.60	12.1	22.70	2.60	1.58	49.6	10.89	2.07	.93	62.5	69.90	1.75	1.32
1.60	1.90	11.0	60.32	2.69	1.76	60.6	19.87	2.18	1.08	50.4	81.23	1.55	1.26
1.90		39.4	87.07	1.23	1.12	100.0	46.34	1.81	1.09	39.4	87.07	1.23	1.12
Head Sample[a]							47.22	1.86	1.16				

a) 1.41 mm x 0 (14 mesh x 0) = 100% of Raw Run of Mine Coal Crushed to 1.41 mm

Peabody Coal Company
Homestead Mine, No. 11 Seam
Ohio County, Kentucky

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

TABLE E-52. 38.1 mm X 149μ ($1^{1}/_{2}$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
Sink	Float	%Wt.	%Ash	%Sulfur Total	%Sulfur Pyritic	%Wt.	%Ash	%Sulfur Total	%Sulfur Pyritic	%Wt.	%Ash	%Sulfur Total	%Sulfur Pyritic
	1.30	51.7	4.44	2.36	1.07	51.7	4.44	2.36	1.07	100.0	13.58	3.72	2.49
1.30	1.40	31.0	11.75	3.30	1.93	88.7	6.69	2.53	1.30	48.3	23.37	5.17	4.00
1.40	1.60	8.1	18.69	5.62	4.39	90.8	8.21	2.97	1.66	17.3	44.18	8.52	7.71
1.60	1.90	1.6	34.00	8.29	7.94	92.4	8.65	3.06	1.77	9.2	66.62	11.07	10.63
1.90		7.6	73.49	11.65	11.20	100.0	13.58	3.72	2.49	7.6	73.49	11.65	11.20
Head Sample[a]							13.72	3.99	2.71				
Final[b]							26.64	2.93	2.17				

a) 38.1 mm x 149μ (1-1/2" x 100 mesh) = 97.3% of Raw Run of Mine Coal Crushed to 38.1 mm

b) 149μ x 0 (100 mesh x 0) = 2.7% of Raw Run of Mine Coal Crushed to 38.1 mm.

TABLE E-53. 9.51 mm X 149μ ($^{3}/_{8}$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
Sink	Float	%Wt.	%Ash	%Sulfur Total	%Sulfur Pyritic	%Wt.	%Ash	%Sulfur Total	%Sulfur Pyritic	%Wt.	%Ash	%Sulfur Total	%Sulfur Pyritic
	1.30	48.2	4.25	2.29	1.05	48.2	4.25	2.29	1.05	100.0	13.47	3.73	2.56
1.30	1.40	30.8	10.57	3.44	2.17	79.0	6.71	2.74	1.49	51.8	2.05	5.07	3.97
1.40	1.60	12.8	24.69	4.80	3.67	91.8	9.22	3.03	1.79	21.0	38.89	7.45	6.62
1.60	1.90	1.5	32.27	9.05	8.20	93.3	9.59	3.12	1.85	8.2	61.06	11.59	11.22
1.90		6.7	67.51	12.16	11.90	100.0	13.47	3.73	2.56	6.7	67.51	12.16	11.90
Head Sample[a]							13.78	3.89	2.76				
Final[b]							19.08	4.22	3.11				

a) 9.51 mm x 149μ (3/8" x 100 mesh) = 98.0% of Raw Run of Mine Coal Crushed to 9.51 mm

b) 149μ x 0 (100 mesh x 0) = 2.0% of Raw Run of Mine Coal Crushed to 9.51 mm.

TABLE E-54. 1.41 mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
Sink	Float	%Wt.	%Ash	%Sulfur Total	%Sulfur Pyritic	%Wt.	%Ash	%Sulfur Total	%Sulfur Pyritic	%Wt.	%Ash	%Sulfur Total	%Sulfur Pyritic
	1.30	48.3	4.70	2.47	.71	48.3	4.70	2.47	.71	100.0	14.79	4.11	2.66
1.30	1.40	25.1	11.61	3.55	2.01	73.4	7.06	2.84	1.15	51.7	24.21	5.64	4.48
1.40	1.60	14.8	20.58	4.19	3.19	88.2	9.33	3.07	1.50	26.6	36.09	7.60	6.81
1.60	1.90	3.8	40.19	7.60	6.68	92.0	10.61	3.25	1.71	11.8	55.55	11.88	11.35
1.90		8.0	62.85	13.92	13.57	100.0	14.79	4.11	2.66	8.0	62.85	13.92	13.57
Head Sample[a]							14.83	4.19	2.73				

a) 1.41 mm x 0 (14 mesh x 0) = 100.0% of Raw Run of Mine Coal Crushed to 1.41 mm

Peabody Coal Company
Ken Mine, #9 Seam
Ohio County, Kentucky

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

TABLE E-55. 38.1 mm X 149µ ($1^1/_2$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	37.5	4.51	2.41	.56	37.5	4.51	2.41	.56	100.0	13.73	3.92	2.23
1.30	1.40	41.3	10.28	3.72	1.87	78.8	7.53	3.10	1.25	62.5	19.26	4.83	3.23
1.40	1.60	12.8	18.84	5.68	4.10	91.6	9.11	3.46	1.65	21.2	36.77	6.99	5.87
1.60	1.90	2.1	29.81	9.53	8.27	93.7	9.58	3.59	1.79	8.4	64.09	8.97	8.57
1.90		6.3	75.51	8.79	8.67	100.0	13.73	3.92	2.23	6.3	75.51	8.79	8.67
Head Sample[a]							13.78	4.34	2.54				
Fine[b]							30.32	4.22	2.51				

a) 38.1 mm x 149µ (1-1/2" x 100 mesh) = 96.4% of Raw Run of Mine Coal Crushed to 38.1 mm.

b) 149µ x 0 (100 mesh x 0) = 1.6% of Raw Run of Mine Coal Crushed to 38.1 mm.

TABLE E-56. 9.51 mm X 149µ ($^3/_8$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	32.6	4.29	2.46	.54	32.6	4.29	2.46	.54	100.0	13.69	4.02	2.34
1.30	1.40	45.2	10.34	3.22	1.46	77.8	7.80	2.90	1.07	67.4	18.23	4.77	3.21
1.40	1.60	13.7	19.90	4.83	3.24	91.5	9.62	3.19	1.40	22.2	34.31	7.94	6.77
1.60	1.90	2.6	29.94	8.45	7.31	94.1	10.18	3.34	1.56	8.5	57.53	12.95	12.45
1.90		5.9	69.69	14.93	14.72	100.0	13.69	4.02	2.34	5.9	69.69	14.93	14.72
Head Sample[a]							13.66	3.96	2.56				
Fine[b]							35.05	4.58	2.32				

a) 9.51 mm x 149µ (3/8" x 100 mesn) = 96.9% of Raw Run of Mine Coal Crusned to 9.51 mm.

b) 149µ x 0 (100 mesh x 0) = 3.1% of Raw Run of Mine Coal Crushed to 9.51 mm.

TABLE E-57. 1.41 mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	35.0	4.08	2.59	.64	35.0	4.08	2.59	.64	100.0	14.18	4.41	2.61
1.30	1.40	37.1	8.85	3.27	1.24	72.1	6.53	2.94	.95	65.0	19.61	5.39	3.67
1.40	1.60	17.8	21.32	5.10	3.43	89.9	9.46	3.37	1.44	27.9	33.92	8.22	6.90
1.60	1.90	2.3	32.00	7.46	6.92	92.2	10.02	3.47	1.55	10.1	56.13	13.71	13.02
1.90		7.8	63.24	15.55	15.09	100.0	14.18	4.41	2.61	7.8	63.24	15.55	15.09
Head Sample[a]							14.12	4.05	2.51				

a) 1.41 mm x 0 (14 mesh x 0) = 100% of Raw Run of Mine Coal Crushed to 1.41 mm

Peabody Coal Company
Star Mine, #9 Seam
Hopkins County, Kentucky

Raw Run of Mine Coal

FLOAT & SINK ANALYSIS (% w/w DRY BASIS)

TABLE E-58. 38.1 mm X 149μ ($1^1/_2$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	40.2	4.24	2.13	.82	40.2	4.24	2.13	.82	100.0	13.36	3.63	2.39
1.30	1.40	40.6	9.55	3.30	1.65	80.8	6.91	2.72	1.24	59.8	19.49	4.64	3.44
1.40	1.60	9.5	20.43	4.76	4.34	90.3	8.33	2.93	1.56	19.2	40.51	7.48	7.23
1.60	1.90	2.0	32.52	6.83	6.50	92.3	8.85	3.02	1.67	9.7	60.17	10.15	10.06
1.90	1.00	7.7	67.35	11.01	10.98	100.0	13.36	3.63	2.39	7.7	67.35	11.01	10.98
Head Sample[a]							13.95	3.77	2.33				
Fine[b]							28.32	4.06	2.00				

a) 38.1 mm x 149μ (1½'' x 100 mesn) = 98.2% of Raw Run of Mine Coal Crushed to 38.1 mm

b) 149μ x 0 (100 mesh x 0) = 1.8% of Raw Run of Mine Coal Crushed to 38.1 mm

TABLE E-59. 9.51 mm X 149μ ($^3/_8$" X 100 mesh)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	40.7	5.92	2.20	.89	40.7	5.92	2.20	.89	100.0	13.24	3.55	2.34
1.30	1.40	41.5	10.83	3.12	1.69	82.2	8.40	2.66	1.29	59.3	18.26	4.48	3.33
1.40	1.60	9.6	16.88	4.12	3.44	91.8	9.29	2.82	1.52	17.8	35.59	7.64	7.15
1.60	1.90	2.7	30.04	7.18	6.58	94.5	9.88	2.94	1.66	8.2	57.49	11.77	11.50
1.90	1.00	5.5	70.97	14.02	13.91	100.0	13.24	3.55	2.34	5.5	70.97	14.02	13.91
Head Sample[a]							13.69	3.65	2.37				
Fine[b]							25.67	4.30	2.30				

a) 9.51 mm x 149μ (3/8'' x 100 mesh) = 97.2% of Raw Run of Mine Coal Crushed to 9.51 mm

b) 149μ x 0 (100 mesh x 0) = 2.8% of Raw Run of Mine Coal Crushed to 9.51 mm

TABLE E-60. 1.41 mm X 0 (14 mesh X 0)

SPECIFIC GRAVITY		FRACTION ANALYSIS				CUMULATIVE RECOVERY FLOAT				CUMULATIVE REJECT SINK			
				%Sulfur				%Sulfur				%Sulfur	
Sink	Float	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic	%Wt.	%Ash	Total	Pyritic
	1.30	41.6	8.31	2.45	1.31	41.6	8.31	2.45	1.31	100.0	13.41	3.72	2.43
1.30	1.40	42.4	9.88	3.09	1.45	84.0	9.10	2.77	1.38	58.4	17.05	4.63	3.23
1.40	1.60	8.6	19.03	4.32	3.40	92.6	10.02	2.92	1.57	16.0	36.03	8.72	7.94
1.60	1.90	2.0	31.02	7.44	6.52	94.6	10.47	3.01	1.67	7.4	55.79	13.83	13.22
1.90		5.4	64.97	16.20	15.70	100.0	13.41	3.72	2.43	5.4	64.97	16.20	15.70
Head Sample[a]													

a) 1.41 mm x 0 (14 mesh x 0) = 100% of Raw Run of Mine Coal Crushed to 1.41 mm

Appendix F

Methods and Trace Element Analysis Data

COAL TRACE ELEMENT ANALYSIS

F.1 GENERAL INTRODUCTION

The initial handling of coal samples is just as important to the final result as the analytical procedures and techniques utilized for the individual determinations. To ensure the validity of the values reported, the following guidelines must be adhered to:

- The composition of all sample handling and grinding equipment must be considered to prevent possible contamination of the sample. For example, stainless grinding equipment must not be used when Ni or Cr are to be determined; similarly, a brass screen should not be used for sieving when Cu is one of the elements of interest.
- All reagent additions must be kept at a minimum; blanks must always be run concurrently; and where possible, high purity reagents should be used.
- Prior to any dissolution, fusion, or ashing that is to be done on the coal, all glassware should be meticulously cleaned. A recommended cleaning procedure is to first wash all glassware with soap (such as Alconox, Dutch Cleanser, etc.) and hot water in order to remove traces of grease and oils. Then, rinse the glassware with deionized or distilled water and place it in a 50% (v/v) nitric acid bath and allow to soak for two hours minimum. This will remove traces of any inorganics that may be left behind by the soap and water washing. Remove from the bath, flush thoroughly with distilled water, follow with acetone rinse, and dry in a clean drying oven at 80°C until dry. Remove from the oven and store in a protected area free of contamination.
- All elements of interest should be completely dissolved by the procedure employed. If not, they must be identified and appropriate steps must be taken in order to ensure complete dissolution.
- Sample solutions should be maintained at pH 2 or less to prevent precipitation. Once the pH is adjusted to this level, the sample solutions must be transferred immediately to polyethylene

containers to minimize adsorption on the walls of glass (Reference 29) and they should be refrigerated (5-10^oC) if it becomes necessary to store them for any period of time.

- Heating of the solutions to effect dissolution should be kept at a minimum and closely controlled. This is to eliminate the possible loss of volatile elements (notably chlorides of Sb, Se, As). Because of this possibility of loss, only HNO_3 should be used and the solutions kept below the boiling point.

F.2 SAMPLE PREPARATION

To ensure both the homogeneity of the sample and to expedite the decomposition of the coal, the coal should be ground to pass a 100 mesh screen in a clean one-quart ball mill. Once the samples have been ground to the required 100 mesh size, they are spread evenly in large petri dishes and dried overnight at 50^oC (± 10^o). Sample decomposition is accomplished using a low temperature oxygen plasma asher (such as International Plasma Corporation Plasma Asher, Model 1001B). This method was chosen over high temperature muffle furnace ashing because at high temperatures, some trace elements may be lost by volatilization (Reference 9).

A needle valve assembly is installed on the purge outlet of the plasma asher in order to control the purge rate and prevent physical loss of the sample by blowing. In the standard operating procedure, both gas flow valves can be initiated simultaneously. However, by doing so, a temperature differential is formed between the two sample chambers. To eliminate this problem, only one gas flow valve is initiated and adjusted to peak operating conditions at a time. When correct adjustment is reached, the other gas valve is initiated and adjusted to start specifications. To prevent sample blowing when the vacuum system is started, a tight seal must be maintained at the chamber door.

Weigh duplicate 2.0 g samples in acid-cleaned petri dish covers. Place the covers and contents into the plasma asher and begin the ashing procedure. Approximately every four hours, open the console and stir the coal sample to expose fresh surface. Ashing is continued 2-3 days or until no black particles remain.

Transfer the sample ash to a Parr Instrument Co. Model 4745 combustion bomb's 24 ml Teflon acid digestion cup by tapping the edges of the petri dish and allowing the ash to flow through a wide-tip funnel into the cup. By first tapping the dish, a minimum of ash will escape into the room atmosphere. Once the bulk of the ash has been removed from the dish, transfer the remaining fine particles of ash by repeated distilled water washings. To minimize the final volume, keep these washings as small as feasible. Six ml of ultra pure concentrated HNO_3 (70% w/w) and 2.5 ml of ultra pure concentrated HF (52% w/w) are then added to the digestion cup. Although Teflon is chemically inert, the surface may contain scratches after repetitive usage which could retain small amounts of material. It is advisable to periodically check the blank by running the $HNO_3 \cdot HF$ directly in the Teflon bomb. If excessive background is encountered, the inside surface should be remachined.

Caution: HF attacks glass so polyethylene or polypropylene pipets or graduated cylinders must be used.

The solution is then placed on an asbestos-covered hot plate at $140^{o}C$ ($\pm 10^{o}$) and evaporated without boiling until the final volume is 50% of the original. The sample cup is then placed in the bomb and the bomb assembled. The bomb is placed in an oven at $130^{o}C$ ($\pm 5^{o}$) for a minimum of four hours.

Remove the sample from the bomb and cool. After cooling, filter the solutions through Whatman #41 filter paper into Nalgene polypropylene volumetric flasks. Polypropylene funnels must also be used. Rinse with a small amount of distilled water. With a small clean rubber policeman, scrape the Teflon inner liner to remove any adhering ash and rinse into filter paper. When filtering is completed, cap the volumetric flasks and transfer the filter paper to platinum crucibles. Ignite the filter paper in a muffle furnace at $800^{o}C \pm 50^{o}C$ until no filter paper ash remains. Remove from oven, allow to cool, then add 2 small scoops of ultra pure Na_2CO_3. Ratio of Na_2CO_3 to residue should be $\sim 10/1$. Fuse the ash and Na_2CO_3 over a burner flame until the crucible is cherry red and the fusion components are in a molten state. Allow to remain at this condition for 1-2 minutes or until complete fusion has taken place.

Remove from flame and allow to cool, then dissolve the fusion cake using a 1:1 HCl/water solution. Filter into the original volumetric flask and repeat washing with the 50% HCl until cake has been completely dissolved. Wash filter paper with the same acid solution and dilute to final 100 ml volume with distilled water.

Ultra pure reagents are used throughout because of their high purity and low ash residues. However, in many cases reagent grade chemicals could be used provided a blank or neat sample is run simultaneously with the unknowns. This would need to be tested in the lab, for it depends on the amount of reagent used, the reagent contamination level and the concentration of the element of interest in the sample.

F.3 ATOMIC ABSORPTION

The analysis of the dissolved coal ash samples for the elements Mn, Cu, Cr, Ni, Sn, Ag, Sb, V, Pb, Cd, Zn, Li, Se, Hg and Be is done by flame or flameless techniques. Atomic Absorption Spectroscopy (AAS) as a general analytical tool is normally considered free of interelement interferences and because of the large dilutions employed, is usually unresponsive to matrix changes. However, trace elemental analysis of coal ash does not follow these general rules because the elements of interest are present in a very dilute form in a relatively concentrated matrix consisting of the major inorganic components of the coal ash, and because of the relatively high concentrations of fluxes and acids needed for the dissolution. These relatively high concentrations encountered as well as the complicated matrix make it mandatory for the analyst to be aware of and to investigate the presence of interferences. The types of interferences encountered are classified into the following three categories (References 18,22):

- Interelement or chemical interferences - for the most part, these interferences, when present, can be eliminated by using a high temperature N_2O-acetylene flame or by addition of suppressants.
- Matrix effects - these interferences are physical in nature and are due to the large concentrations of acids and solids in solution. These effects are compensated for by specially preparing the standards to match the expected acid and salt content of the sample.

- Molecular absorption - this type of spectral interference can be particularly troublesome when determining trace elements in solutions of high salt content. Molecular absorptions predominately occur from species such as CaOH or SrO and result in a positive error in the absorption measurement. The Jarrell-Ash 810 AA or equivalent is especially suited for the evaluation and elimination of this type of interference. This is accomplished by first ascertaining the presence of the interference by monitoring a nonabsorbing wavelength near the wavelength of interest on a second channel. This molecular absorption when present is visually recorded on a strip chart recorder concurrently with the absorption of the desired element. The interference is then subtracted from the combined signal.

The solutions prepared as per section F.2 can be analyzed directly by AAS for Mn, Cu, Cr, Ni, Sn, Ag, Sb, V, Pb, Cd, Zn, Li, Se and Be using the operating conditions specified in Table F-1. Background correction must be used for Cd and in some instances for Mn, Be, Zn, and Sb. In all cases, the standards employed for calibration of the instrument must contain the same quantities of HNO_3-HF, Na_2CO_3 and HCl used in the preparation of the samples.

F.3.1 Arsenic Analysis (References 15,16,17,27,28,33)

F.3.1.1 Summary

A sample of coal is mixed with MgO and combusted at 550°C in a muffle furnace. The residue is transferred to a 125 ml Erlenmeyer flask and treated with HCl and KI. The arsenic is then volatilized as arsine, using $SnCl_2$ and Zn, and absorbed in a silver diethyldithiocarbamate pyridine solution. The quantitative determination is then performed by comparing the absorbance of the developed color at 540 nm to standards.

F.3.1.2 Reagents

- 15% KI - 15 g KI dissolved in 100 ml D.I. water
- 20% $SnCl_2$ - 20 g $SnCl_2$ dissolved in 100 ml HCl, heat slowly to effect dissolution

Table F-1.

ATOMIC ABSORPTION ANALYTICAL PARAMETERS

Element	Analytical λ	Slit Å	Background λ	Slit Å	Flame Conditions	Detection Limit (ppm) Based on 2 g	Reported Interferences	Method of Interference Removal	References
Mn	2795	4	2882	4	Air-acetylene	0.15	Si, and molecular absorbance by K, Na, Cr	Ca at 2000 ppm or use background correction	15,16,17,18, 22,24,26,35, 36
Cu	3247	10	3171	10	Air-acetylene	0.25	Ca molecular adsorption	Use background correction	15,16,18,22, 23,26,35,36
Cr	3579	4	3563	4	N_2O-acetylene	0.25	Ni, Fe, pH	N_2O acetylene flame or addition of 2% NH_4Cl	15,17,18,22, 32,35,36
Ni	2320	2	2316	2	N_2O-acetylene	0.5	Fe, Cr, Ca molecular adsorption	Use background correction or N_2O acetylene flame	17,18,22,26 36
Sn	2246	4	2186	4	Hydrogen-air	2.5	H_2SO_4, H_3PO_4, 5000 ppm Na	Keep acid concentration constant	18,22
Ag	3281	10	3257	10	Air-acetylene-lean	0.25	Th, H_2SO_4, H_3PO_4	Keep sample well diluted	18,22
Sb	2176	4	2241	4	Air-acetylene-lean	5.0	Cu at 1000 ppm		18,22
V	4408	2			N_2O-acetylene	5.0	H_3PO_4		18,21,22
Pb	2833	10	2850	10	Air-acetylene-lean	1.5	200 ppm Ni, Cr, Mo, Si gave slight interference, $PO_4^{=}$ $SO_4^{=}$, formate, phthalate	Use EDTA	15,17,18,22, 26,35,36
Cd	2288	4	2297	4	Air-acetylene-lean	0.15	Molecular adsorption by Ca, Mg, Na, K and Fe	Use background correction	15,17,18,20, 22,23,26,35
Zn	2139	10	2197	10	Air-acetylene-lean	0.15	Ca, Na, K, Mg, and Fe molecular absorptions	Use background correction	15,16,17,18, 22,23,26,35, 36
Li	6708	10	6698	10	Air-acetylene-lean	0.1	Sr at 50 ppm		18,22
Be	2349	10	2312	10	N_2O-acetylene	0.025	None reported		15,18,22,37
Se	1960	10	1879	10	Hydrogen-argon	5.0	None reported		18,22
Fe	2482	2	2511		Air-acetylene	2.5	Molecular absorbance	Use background correction	18,22
Ca	4227	10			N_2O-acetylene	3.5	Sulfate, phosphate aluminum and silica	Add 1% La or use N_2O-acetylene flame	16,17,18,22
Mg	2852	10			Air-acetylene	0.2	Same as for calcium	Add 1% La	18,22

- Acidified water - 5 ml conc. H_2SO_4 in 500 ml water
- MgO - Reagent
- Zn - 40 mesh granular
- Lead acetate solution - saturated in water
- Silver diethyldithiocarbamate, pyridine solution - 5 g in one liter of pyridine. Allow solution to stand in a covered container for 48 hours. Filter through a Whatman #40 filter and store over molecular sieves in a brown bottle.

F.3.1.3 Procedure

To a porcelain crucible, add 1.0 g sample and 0.1 g MgO, and mix. To another procelain crucible, add 1.0 g and no sample. This will be used later for the blank. Place all crucibles into a muffle furnace and heat slowly to 550°C and maintain at this temperature for 1-1/2 hours. Remove from oven and allow to cool. Transfer to a wide mouthed Erlenmeyer flask using three 5 ml rinsings of acidified water. Before transferring, wet the sample by slowly rinsing down the sides of the crucible with the acidified water. Repeat until the sample is completely wetted. Wash crucible with the acid water solution until an approximate volume of 50 ml is attained. Repeat, following the same procedure for the blank.

To all the flasks, add 5.0 ml conc. HCl, 2.0 ml of the 15% KI solution, and 1.0 ml of the 20% $SnCl_2$ solution. Allow the solutions to stand for 15 minutes. At the end of this time, the reaction flasks are connected to a receiving flask by a tube containing glass wool to which a few drops of a saturated lead acetate scrubbing solution has been added. Ten ml of the silver diethyldithiocarbamate solution is added to the receiving flask and 3 grams granular zinc is added to the reaction flasks. Connect the reaction and receiving flask together in as short a time as possible to prevent any arsine gas loss. After allowing 30 minutes for complete gas evolution, remove vessel and mix the solution by bubbling nitrogen through the solution to remove any residue that is adhering to the side wall. Transfer the absorbing solution to 1 cm quartz cells and measure its absorbance at 540 nm against the blank reagent using a spectrophotometer.

F.3.1.4 Standard Curve

Before running As determinations, prepare a 100 ppm As stock solution (10 ml of 1000 ppm As and dilute to 100 ml with distilled water). Once the stock solution is prepared, take 1, 2, 5 and 10 mls of the 100 ppm standard, transfer to four 100 ml volumetric flasks and dilute to marks with distilled water. These 1, 2, 5 and 10 ppm As solutions are the working standards.

Place one gram of MgO in each of five ceramic crucibles and heat in a 550°C muffle for 1-1/2 hours. Remove and cool, then transfer to a

125 ml Erlenmeyer with acidified water. Pipet one ml of each of the four standards into the respective Erlenmeyers and one ml of distilled water into a fifth Erlenmeyer for a blank, and proceed according to the procedure in F.3.2.3. Note the following:

1) The pyridine - silver diethyldithiocarbamate solution will deteriorate slightly, and if not filtered, will lead to erratic values.
2) The type of mesh zinc used appears to have some bearing on the arsine evolution. Therefore, only one bottle should be designated for use and a new calibration curve should be run when another bottle is employed.
3) Heating the reaction solution facilitates the evolution of arsine and has proved helpful in improving the accuracy of the analysis.

F.3.2 Boron (References 15,16,29,30,33)

F.3.2.1 Summary

Gently ash the coal at 550°C, then fuse the ash with Na_2CO_3. After dissolving the fusion mixture in HCl, the boric acid is extracted with 2-ethyl-1,3-hexanediol and determined as the rosocyanine complex in 95% ethanol. This procedure is applicable to coals containing between 1-400 ppm B.

F.3.2.2 Reagents

- 10 ppm standard boron solution - prepare by appropriate dilution of 1000 ppm stock boron solution
- 2-ethyl-1,3-hexanediol - 10% solution in chloroform
- Curcumin reagent - 0.375% (w/v) dissolved in glacial acetic acid, filtered, and stored in a darkened polyethylene bottle
- Ethanol - 95% reagent grade
- Sulfuric acid - high purity (Van Waters and Rogers Ultrex grade)
- Na_2CO_3 - high purity (Van Waters and Rogers Ultrex grade)
- 1N HCl - use high purity acid and distilled water

F.3.2.3 Procedure

Weigh 1 g coal ± 0.1 mg into a platinum crucible; ash at 550°C for one hour. Fuse residue with 1 g of Na_2CO_3, then dissolve the melt with 1N HCl and dilute to 100 ml. Pipet 2 ml of this solution into a 10 ml Nalgene centrifuge tube and extract, by shaking with 2 ml of 2-ethyl-1,3-hexanediol in $CHCl_3$. Syringe off the liquid phase, and pipet 0.5 ml of the organic phase into a 50 ml Nalgene volumetric flask. Add 1 ml of curcumin reagent followed by 0.3 ml of conc. H_2SO_4 and allow to react for 15 minutes. Adjust volume to 50 ml with reagent grade 95% ethanol and read absorbance at 500 nm against 95% ethanol. Run a reagent blank concurrently and subtract this absorbance from the sample absorbance. The boron concentration of the sample is calculated from a standard curve using the adjusted sample absorbance reading.

F.3.2.4 Standardization

Prepare standard solutions containing 0.1, 0.2, 0.5, 1.0, 2.0 and 3.0 ppm boron by appropriate dilution of the 10 ppm standard. Pipet 2 ml of prepared standard into a Nalgene centrifuge tube and proceed as per general procedure. Note that all apparatus is to be washed with 1:1 aqueous HNO_3.

F.3.3 Fluoride Analysis (References 9,15,31,34)

F.3.3.1 Summary

Coal is mixed with benzoic acid, pressed into a pellet and combusted in a Parr bomb and the combustion gases scrubbed with a dilute caustic solution. The pH of the solution is now adjusted to 5.2-5.3, and CO_2 is expelled by gentle heating. The fluoride concentration is then determined after pH readjustment and addition of a citrate - KNO_3 buffer solution using a specific ion electrode procedure.

F.3.3.2 Results

- 1N NaOH - prepared from high purity reagents
- 0.5N H_2SO_4 - prepared from high purity reagents

- 1M sodium citrate, 0.2M KNO_3 buffer solution - dissolve 294 g of citric acid trisodium salt dihydrate and 20 g of KNO_3 in one liter of high purity water (pH 6.3)
- Fluoride standard - prepare a series of fluoride standards in the following molar concentrations, .0005, .001, .005, .01, .05 and .10, by dissolving high purity KF in the citrate–KNO_3 buffer.

F.3.3.3 Procedure

Mix a 1 gram coal sample, ground to pass a 100 mesh screen, with approximately 0.25 g benzoic acid (primary standard) and place in a fused quartz sample holder within a Parr combustion bomb that contains 10 ml of 1N NaOH. The bomb is pressurized to about 28 atmospheres and then fired. At leased 15 minutes are allowed to elapse before the bomb is depressurized. Three approximate 5 ml aliquots of distilled water are used to rinse the bomb contents into a 50 ml plastic beaker (plastic-ware is used from this point on).

The beaker contents are magnetically stirred with a Teflon bar while the pH is adjusted to 5.2-5.5 with 0.5N H_2SO_4. (The initial pH before adjustment will be about 7.0). The beaker is then placed in a hot water bath for about 10 minutes, removed, and again stirred to drive off most of the dissolved CO_2. Five ml of the sodium citrate - KNO_3 buffer solution is added to the beaker contents. The total volume is adjusted to 50 ml with distilled water and cooled to room temperature. At this time, the potential is read using a fluoride specific ion electrode vs a saturated calomel reference electrode. In some cases, about 10 minutes are required for equilibrium to be reached. Then 1 ml of 0.01M F is added and the potential of the solution is again read.

The pH is quite critical for the initial potential reading. At 5.0-5.5, final results tend to be low because of F^- complexing with H^+. Above 6.5, final results tend to be high because of interference by OH^- or HCO_3^- at 1000 to 1 concentration over the F^-.

The concentration of fluoride in the coal sample is calculated using the following formulas:

$$F\ (\text{soln}) = \frac{\Delta F}{\exp\ (\Delta E/S) - 1}$$

$$F\ (\text{coal}) = \frac{50 \times F\ \text{soln} - (WB \times FB)}{\text{wt coal}}$$

Where ΔF = change in F conc. due to addition of spike = 3.8 ppm

ΔE = change in potential readings = $E_2 - E_1$

S = slope of mv vs ln (F^-) concentration for the electrode = -22.95

WB = weight benzoic acid

FB = F^- content of benzoic acid = 7.15 ppm

F.3.4 Mercury Analysis (References 18,19,22,25,38)

F.3.4.1 Summary of Method

A coal sample is decomposed by burning in a combustion bomb containing a dilute nitric acid solution under 24 atmospheres of oxygen pressure. After combustion, the bomb washings are diluted to a known volume, and mercury is determined by atomic absorption spectrophotometry using a flameless cold vapor technique.

F.3.4.2 Apparatus

- Oxygen bomb - Standard 360 ml stainless steel combustion bomb as used for coal calorimetry (ASTM D 2015).
- Combustion crucible - Vycor or quartz crucible of proper size to fit the bomb sample holder (A.H. Thomas No. 3879-C or equivalent).
- Firing wire - No. 34 B & S gauge nickel-chromium alloy wire, 10 cm length.

- Firing circuit - as described in ASTM D 2015.
- Atomic Absorption Spectrophotometer - Use mercury hollow cathode lamp and a wavelength of 253.7 nm.
- Absorption cell - a cylindrical tube of approximate dimensions 25 mm I.D. X 125 mm long, with quartz windows, and incorporating inlet and outlet sidearms to permit introduction and discharge of carrier gas. This type of cell is available commercially from several manufacturers of atomic absorption equipment, or it may be constructed from readily available materials (Note 1). In the latter case, the cell should be tested carefully for possible leakage after assembly. The cell is mounted in the optical path of the AA spectrophotometer.
- Mercury reduction vessel - a cylindrical, flat-bottom cold test jar (Fisher No. 13-415 or equivalent), containing a glass or polypropylene covered magnetic stirring bar, and incorporating a two-hole rubber stopper through which are passed a gas bubbler tube (Note 1) and a short gas outlet tube. The bubbler tube is connected to the carrier gas source, and the outlet tube is connected to the absorption cell; all connections should be made with polypropylene tubing (Note 2). Calibrate the reduction vessel at the 50 ml mark.
- Magnetic stirrer - for use in conjunction with the mercury reduction vessel.
- Flowmeter - capable of measuring gas flows in the range of one liter per minute.

Note 1 - A constricted, open gas bubbler tube is preferred over the fritted glass dispersion type. With the latter, there is the possibility of mercury retention in the frit, at least if the solution is not stirred sufficiently.

Note 2 - There is some evidence that certain materials such as Tygon and Teflon can adsorb mercury to a significant extent. For this reason, the use of standard Teflon-covered stirring bars is also discouraged.

F.3.4.3 Reagents

- Stock mercury solution, approximately 1 gram/liter (1,000 ppm). Weigh 1 gram of pure, elemental mercury to the nearest 0.1 mg and dissolve in a solution consisting of 150 ml of distilled water and 50 ml of concentrated HNO_3 (sp. gr. 1.42). Dilute this solution to 1000 ml with distilled water. The final solution contains approximately 1,000 ppm of mercury (record exact concentration) in a matrix of 5% (v/v) nitric acid.
- Standard mercury solutions - Prepare working standard solutions of mercury down to 1 ppm by serial dilutions of the 1,000 ppm Hg stock solution with 5% HNO_3. Such solutions may be assumed to be stable for up to one week. Below 1 ppm Hg, standard solutions should be prepared daily and diluted with 5% HNO_3 and/or distilled water as appropriate, so that the final solution matrix is approximately 1% HNO_3.
- Nitric acid solution, 10% (v/v) - Dilute 100 ml of concentrated HNO_3 (sp. gr. 1.42) to 1000 ml.
- Stannous chloride solution, 10% (w/v) - Dissolve 10 g of $SnCl_2 \cdot 2H_2O$ in 10 ml of concentrated HCl (warm the solution if necessary to accelerate the dissolution process) and dilute to 100 ml. Add a few pieces of metallic tin.
- Helium carrier gas - Use Matheson High Purity grade or equivalent. The gas may contain a trace amount of mercury, and the use of a small amalgamator trap (gold or silver wire coils packed in about 1 inch of tubing) between the gas cylinder and the flowmeter is advisable.

F.3.4.4 Standardization

Transfer an aliquot of a standard mercury solution containing 0.10 micrograms of mercury to the mercury reduction vessel. Dilute to 50 ml with 10% HNO_3, and add 5 ml of 10% stannous chloride solution. Insert the stopper containing the carrier gas inlet and outlet tubes, and start the magnetic stirrer. Stir the solution for one minute, then initiate helium flow at a rate of one liter per minute (Note 3). Record the absorption peak and measure peak height. Repeat this procedure using varying amounts of mercury throughout the range of 0.01 to 1.00 micrograms.

Run a blank using all reagents except the standard mercury solution. Plot absorption (peak height) against micrograms of mercury present, after correcting for the reagent blank, to establish a working curve.

F.3.4.5 Procedure

Mix 1 g of coal and ∿0.25 g of benzoic acid. Press into a pellet and place in a fused quartz crucible. Transfer 10 ml of 10% nitric acid to the bomb, place the crucible in the electrode support of the bomb, and attach the fuse wire. Assemble the bomb and add oxygen to a pressure of 24 atmospheres (gauge). Place the bomb in the calorimeter (a cold water bath in a large stainless steel beaker is also satisfactory) and ignite the sample using appropriate safety precautions ordinarily employed in bomb calorimetry work.

After combustion, the bomb should be left undisturbed for 10 minutes to allow temperature equilibration and the absorption of soluble vapors. Release the pressure slowly and transfer the contents of the bomb (and crucible) to the mercury reduction vessel by washing with 10% nitric acid (Note 4).

Rinse the bomb, electrodes, and crucible thoroughly with several small washings of 10% nitric acid, then dilute the contents of the reduction vessel with 10% nitric acid to a total volume of 50 ml. Proceed with the determination as described under Standardization. Determine the amount

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Note 3 - The optimum flow rate will depend on the size of the absorption cell. Several flow rates should be tried until maximum sensitivity is obtained.

Note 4 - If there is any question as to whether the sample has undergone complete oxidation during combustion, add 5% potassium permanganate solution dropwise until a pink color persists.

of mercury in micrograms and divide by the sample weight in grams to obtain the mercury value in parts per million.

As the bomb ages, there may be a tendency for mercury to become trapped in the bomb wall fissures during combustion. In addition, if the same bomb is used for normal calorimetry work, there may be a tendency for mercury to accumulate in the bomb with time. Consequently, before a series of mercury determinations is undertaken, several blank determinations should be made by firing benzoic acid pellets (approximately 1 gram) in place of the coal. Benzoic acid firings should be repeated until a stable, consistently low blank value is obtained. This final blank value is then used to correct the mercury values obtained for subsequent coal samples (Note 5).

F.4 ANALYSIS RESULTS

The results of trace element analyses for 18 elements in ten coals before and after treatment by the Meyers and float-sink procedures are presented in Tables F-2 to F-11. All analyses were run in duplicate on both untreated and treated coals in order to get a good estimate of precision of the results and a reliable estimate of the trace element removal. These analyses were run on two samples of untreated coal in order that all sources of error such as sampling, ashing, dissolution, handling, and final analysis would be included in the final precision estimate. In a similar manner, two samples each of the extracted and float-sink separated coal samples were each analyzed once for two sets of two values on the treated coal.

A standard deviation was then calculated for each set of results and was then used to determine which results should be discarded. A value falling outside 2σ of the mean was not used. Discarded values are in parentheses in the data tables. The differences between the initial

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Note 5 - The condition of the interior of the bomb should be inspected at frequent intervals. If evidence of significant pitting or corrosion is observed (usually indicated by erratic mercury values for samples or benzoic acid blanks) the bomb should be returned to the manufacturer for reconditioning.

average and the final average value are also presented in the tables. The deviations of the differences were calculated using Equation 1:

$$\sigma_{a-b} = \sqrt{\sigma_a^2 + \sigma_b^2} \qquad (1)$$

Also reported are the calculated % removals. The standard deviation for the amount removed was calculated using Equation 2:

$$\sigma_{(a-b)/a} = \sqrt{\frac{b^2}{a^4} \cdot \sigma_a^2 + \frac{1}{a^2} \cdot \sigma_b^2} \qquad (2)$$

In cases where $\sigma_{(a-b)/a}$ is larger or the same as the value of the % difference, N.D. is entered in the % Loss column to indicate that any apparent difference in the initial and final values is not statistically valid. In all cases where the elment was not detected in the starting coal, "Ind" appears in the PPM Change and % Loss columns.

Table F-2

TRACE ELEMENT ANALYSIS (PPM)

MUSKINGUM MINE, MEIGS CREEK NO. 9 SEAM, MORGAN COUNTY, OHIO

Element	Individual Values							Average Values			PPM Change		% Loss	
	Raw Coal			Treated Coal				Raw Coal	Treated Coal		Meyers Process	Float-Sink	Meyers Process	Float-Sink
				Meyers Process		Float-Sink			Meyers Process	Float-Sink				
Ag	1.7	3.5	1.7	0.7	0.2	<1	<1	2.3±1.04	0.4±0.35	<1	1.9±1.1	>1.3±1	83±17	>57±20
As	2.0	-	1.9	-	-	2.0	2.0	2.0±0.07	- -	2.0±0	- -	0±0.1	- -	N.D.
B	48	-	60	80	60	30	30	54±8.5	70±14.1	30±0	+16±16.5	24±8.5	N.D.	44±7
Be	1.7	2.2	2.1	2.0	1.7	2	3	2.0±0.26	1.8±0.21	2.5±.071	0.2±0.33	+0.5±0.27	N.D.	Gain
Cd	1.5	1.7	(0.1	0.6	0.4	2	2	1.6±0.14	0.5±0.14	2±0	1.1±0.20	+0.4±0.14	67±14	Gain
Cr	121	95	114	56	47	64	58	110±13.5	52±6.4	61±4.2	58±14.9	49±14.1	53±8	45±8
Cu	14	16	15	12	19	20	19	15±1.0	16±4.9	19.5±0.7	+1±5.0	+4.5±1.2	N.D.	Gain
F	116	-	118	165	180	90	78	117±1.4	172±10.6	84±8.5	+56±10.7	33±8.5	Gain	28±7.2
Hg	0.10	-	0.08	-	-	-	-	0.09±0.014	- -	- -	- -	- -	-	- -
Li	55	53	58	58	37	16	15	55±2.5	48±14.8	16±0.7	7±15.0	39.5±2.6	N.D.	72±1.8
Mn	26	24	26	7.7	4.8	30	25	25±1.2	6.3±2.1	28±3.5	18.7±2.9	+3.0±3.7	75±9	N.D.
Ni	25	33	30	21	13	47	41	29±4.0	17±5.7	44±4.2	12±7.0	+15±5.8	41±21	Gain
Pb	13	11	12	289	144	32	32	12±1.0	216±103	32±0	+204±103	+20±1	Gain	Gain
Sb	<5	-	<5	<5	<5	49	36	<5	<5	42±9.2	Ind	>+37	Ind	Gain
Se	64	-	54	<1	<1	-	-	59±7.1	<1	- -	- -	- -	- -	- -
Sn	20	16	10	16	30	31	41	15±5.0	23±9.9	36±7.1	+8±11.1	+21±8.7	N.D.	Gain
V	37	33	28	38	16	37	49	33±4.5	27±15.6	43±8.5	6±16.2	+10±9.6	N.D.	N.D.
Zn	34	27	30	12	13	22	20	30±3.5	12±0.7	18±3.6	18±3.6	12±5.0	60±5	40±14

Table F-3

TRACE ELEMENT ANALYSIS (PPM)

MATHIES MINE, PITTSBURGH SEAM, WASHINGTON COUNTY, PENNSYLVANIA

Element	Individual Values							Average Values			PPM Change		% Loss	
	Raw Coal			Treated Coal				Raw Coal	Treated Coal		Meyers Process	Float-Sink	Meyers Process	Float-Sink
				Meyers Process		Float-Sink			Meyers Process	Float-Sink				
Ag	2.2	2.0	1.2	0.2	0.2	1	1	1.8±0.53	0.2±0.0	1±0	1.6±0.53	0.8±0.53	89±3	44±16
As	7.1	-	5.1	1.0	1.0	<.1	.3	6.1±0.41	1.0±0.0	0.18±0.18	5.1+0.41	5.9±0.45	84±1	97±3
B	48	-	60	58	60	50	45	54±8.5	59±1.4	48±3.5	5.0±8.6	6±9.2	N.D.	N.D.
Be	2.6	2.7	2.7	1.6	1.9	3	2	2.7±0.06	1.8±0.21	2.5±0.71	0.9±0.22	0.2±0.71	33±8	N.D.
Cd	0.7	1.1	0.5	<0.5	<0.5	4	4	0.8±0.31	<0.5	4±0	>.3±0.3	+3.2±0.31	>38±24	Gain
Cr	114	-	106	53	58	47	49	110±5.7	56±3.5	48±1.4	54±6.7	62±5.9	49±4	56±3
Cu	31	30	27	23	20	20	18	29±2.1	22±1.7	19±1.4	7±2.7	10±2.5	24±8	34±7
F	222	-	197	200	219	82	94	210±17.7	210±13.4	88±8.5	0±22.2	122±19.6	N.D.	58±5
Hg	0.08	-	0.10	-	-	-	-	0.09±0.014	- -	- -	- -	- -	- -	- -
Li	70	60	62	38	42	24	28	64±5.3	40±2.8	26±2.8	24±6.0	38±6.0	38±7	59±6
Mn	64	73	62	5.0	8.4	24	23	66±5.9	6.7±2.4	23.5±0.71	59±6.4	43±5.9	90±4	64±3
Ni	35	35	33	16	15	46	38	34±1.2	16±0.7	42±5.7	18±1.4	+8±5.8	53±3	N.D.
Pb	25	17	15	<5	10	36	30	19±5.3	6±5.3	33±4.2	13±7.5	+14±6.6	68±30	Gain
Sb	<5	<5	<5	<5	<5	54	46	<5	<5	50±5.7	Ind	>45±5.7	Ind	Gain
Se	78		69	<1	4	-	-	74±6.4	2±2.8	- -	- -	- -	- -	- -
Sn	14	-	10	<5	<5	79	77	12±2.8	<5	78±1.4	>7±2.8	+66±3.1	>58±10	Gain
V	46	68	65	15	33	14	29	60±11.9	24±12.7	22±10.6	36±17.4	38±15.9	60±23	63±19
Zn	41	41	40	12	13	21	26	41±0.6	12±0.7	24±3.5	29±0.9	21±.9	71±2	41±9

Table F-4

TRACE ELEMENT ANALYSIS (PPM)

ROBINSON RUN MINE, PITTSBURGH SEAM, HARRISON COUNTY, WEST VIRGINIA

Element	Individual Values						Average Values			PPM Change		% Loss	
	Raw Coal		Treated Coal				Raw Coal	Treated Coal		Meyers Process	Float-Sink	Meyers Process	Float-Sink
			Meyers Process		Float-Sink			Meyers Process	Float-Sink				
Ag	1.5	1.7	1.5	1.0	1	1	1.6±0.14	1.2±2.35	1±0	0.4±0.38	0.6±0.14	N.D.	38±5
As	6.2	5.6	<0.3	<0.3	1	1	5.9±0.42	<0.3	1±0	>5.6±0.4	4.9±0.42	>95±1	83±1
B	60	60	75	95	60	60	60±0	85±14.1	60±0	+15±14.1	0±0	N.D.	N.D.
Be	1.0	0.3	0.7	1.3	<0.5	<0.5	0.6±0.49	1.6±0.42	<0.5	+0.4±0.65	>0.1±0.49	N.D.	N.D.
Cd	1.6	2.1	1.6	0.9	3	3	1.8±0.35	1.2±0.49	3±0	0.6±0.60	+1.2±0.35	N.D.	Gain
Cr	102	98	37	37	29	32	100±2.8	37±0	30±2.1	63±2.8	70±3.5	63±1	70±2
Cu	10	10	17	21	16	13	10±0	19±2.8	14±2.1	+9±2.8	+4±2.1	Gain	Gain
F	114	88	68	94	113	82	100±18.4	81±18.4	98±22	19±26.0	2±29	N.D.	N.D.
Hg	0.13	0.14	-	-	-	-	0.14±0.007	- -	- -	- -	- -	-	-
Li	15	9	8	8	5	5	12±4.2	8±0	5±0	4±4.2	7±4.2	33±23	58±15
Mn	41	42	8.1	6.2	24	23	42±0.7	7.1±1.3	24±0.7	35±1.5	18±1.0	83±3	43±2
Ni	26	27	20	16	39	29	26±0.7	18±2.8	34±7.1	8±2.9	+8±7.1	31±1	N.D.
Pb	13	12	20	17	23	21	12±0.7	18±2.1	22±1.4	+6±2.2	+10±1.6	Gain	Gain
Sb	20	18	4	2	44	32	19±1.4	3±1.4	38±8.5	16±1.9	+18±8.6	84±7	Gain
Se	40	58	22	13	-	-	49±12.7	18±6.4	- -	31±14.2	- -	-	-
Sn	15	<5	<5	<5	68	91	8	<5	80±16.2	Ind	>38	Ind	Gain
V	28	28	2	7	<5	7	28±0	4±3.5	5±3.2	24±3.5	23±3.2	86±12	82±11
Zn	32	28	11	10	21	14	30±2.8	16±0.7	18±5.0	14±2.9	12±5.7	47±5	40±18

Table F-5

TRACE ELEMENT ANALYSIS (PPM)

POWHATTAN NO. 4 MINE, PITTSBURGH NO. 8 SEAM, MONROE COUNTY, OHIO

Element	Individual Values						Average Values			PPM Change		% Loss	
	Raw Coal		Treated Coal				Raw Coal	Treated Coal		Meyers Process	Float-Sink	Meyers Process	Float-Sink
			Meyers Process		Float-Sink			Meyers Process	Float-Sink				
Ag	0.7	1.0	2.0	2.0	1.0	0.5	0.8±0.21	2.0±0.00	0.8±0.35	+1.2±0.21	0±0.41	Gain	N.D.
As	4.6	4.0	-	-	2	2	4.3±0.42	- -	- -	- -	- -	-	-
B	65	60	87	87	50	50	62±3.5	87±0.1	50±1	+25±3.5	12±3.6	Gain	19±5
Be	3.6	3.0	2.3	2.3	1	3	3.3±0:42	2.3±0.0	2±1.4	1±0.42	1.3±1.5	30±9	N.D.
Cd	1.1	1.4	1.0	0.5	4	2	1.2±0.21	0.8±0.35	3±1.4	+1.8±1.4	0.4±0.41	N.D.	Gain
Cr	139	143	82	86	61	62	141±2.8	84±2.8	62±0.7	57±4.0	79±2.9	40±2	56±1
Cu	24	26	31	19	23	18	25±1.4	25±8.5	20±3.5	0±8.6	5±3.8	N.D.	20±15
F	281	282	219	216	115	118	282±0.7	218±2.1	116±2.1	64±2.2	166±2.2	23±1	59±1
Hg	0.07	0.07	-	-	-	-	0.07±0.00	- -	- -	- -	- -	-	-
Li	53	51	48	46	16	18	52±1.4	47±1.4	17±1.4	5±2.0	35±2.0	10±4	67±3
Mn	56	58	16	16	30	28	57±1.4	16±0	29±1.4	41±1.4	28±2.0	72±1	49±3
Ni	36	38	32	22	48	26	37±1.4	27±7.1	37±15.6	10±7.2	0±15.6	27±19	N.D.
Pb	23	18	225	215	40	26	20±3.5	220±7.0	33±9.9	+200±7.8	+13±10.5	Gain	N.D.
Sb	<1	7	2	<5	45	25	<6	<1.5	35±14.1	Ind	>+30	Ind	Gain
Se	53	54	6	27	-	-	54±0.7	16±14.9	- -	- -	- -	-	-
Sn	<5	<5	23	47	49	38	<5	35±17.0	44±7.8	>+30	>+39	Gain	Gain
V	56	65	63	59	42	40	60±6.4	61±2.8	41±1.4	+1±7.0	19±6.6	N.D.	32±8
Zn	40	39	26	16	24	22	40±0.7	21±7.1	23±1.4	19±7.1	17±1.6	48±18	42±4

Table F-6

TRACE ELEMENT ANALYSIS (PPM)

DELMONT MINE, UPPER FREEPORT SEAM, WESTMORELAND COUNTY, PENNSYLVANIA

Element	Individual Values						Average Values			PPM Change		% Loss	
	Raw Coal		Treated Coal				Raw Coal	Treated Coal		Meyers Process	Float-Sink	Meyers Process	Float-Sink
			Meyers Process		Float-Sink			Meyers Process	Float-Sink				
Ag	3.0	2.2	2.8	5.9	1	1	2.6±0.57	4.4±2.19	1±0	+1.8±2.3	1.6±0.57	N.D.	62±8
As	40	41	1	1	12	10	40±0.7	1±0	11±0.7	39±0.7	29±1.0	98±1	73±2
B	15	20	15	27	5	5	18±3.5	21±8.5	5±0	+3±9.2	13±3.5	N.D.	72±5
Be	4.0	4.3	3.6	3.4	2	2	4.2±0.21	3.5±0.14	2±0	0.7±0.25	2±0.21	17±5	52±2
Cd	1.7	2.0	1.3	1.0	3	3	1.8±0.21	1.2±0.21	3±0	0.6±0.30	+1.2±0.21	33±14	Gain
Cr	146	141	75	87	50	54	144±3.5	81±8.5	52±1.4	63±9.2	92±3.8	44±6	64±1
Cu	20	21	20	22	11	11	20±0.7	21±1.4	11±0	+1±1.6	9±0.7	N.D.	45±2
F	125	137	126	131	55	54	131±8.5	128±3.5	54±0.7	3±9.2	77±8.5	N.D.	59±3
Hg	<0.2	<0.2	-	-	-	-	<0.2	- -	- -	- -	- -	-	-
Li	24	24	23	24	9	10	24±0	24±0.7	10±0.7	0±0.7	14±0.7	N.D.	58±3
Mn	94	94	10	12	35	35	94±0	11±1.4	3.5±0	83±1.4	90±0	88±1	96±1
Ni	66	70	35	45	21	22	68±2.8	40±7.1	22±0.7	28±7.6	46±2.9	41±1	68±2
Pb	31	31	27	47	18	17	31±0	37±14.1	18±1.4	+6±14.1	13±1.4	N.D.	42±5
Sb	11	21	4	5	14	15	16±7.1	4±0.7	1.4±0.7	12±7.1	15±7.1	75±12	91±6
Se	26	24	<1	<1	-	-	25±1.4	<1	- -	- -	- -	- -	-
Sn	16	23	9	21	34	38	20±5.0	15±8.5	36±2.8	5±9.9	+16±5.7	N.D.	Gain
V	41	40	46	48	14	11	40±0.7	47±1.4	12±2.1	+7±1.6	+16±5.7	Gain	Gain
Zn	76	76	35	30	63	65	76±0	32±3.5	64±1.4	44±3.5	12±1.4	58±5	16±2

Table F-7

TRACE ELEMENT ANALYSIS (PPM)

MARION MINE, UPPER FREEPORT SEAM, INDIANA COUNTY, PENNSYLVANIA

Element	Individual Values						Average Values			PPM Change		% Loss	
	Raw Coal		Treated Coal				Raw Coal	Treated Coal		Meyers Process	Float-Sink	Meyers Process	Float-Sink
			Meyers Process		Float-Sink			Meyers Process	Float-Sink				
Ag	1.5	1.5	<1	<1	<1	<1	1.5±0.0	<1	<1	>0.5	>0.5	>33	>33
As	9.5	10.0	<.3	<.3	8	7	9.8±0.35	<0.3	8±0.7	>9.5	1.8±.78	97±4	18±8
B	5.0	14.9	5.0	14.9	10	10	10±7.0	10±7.0	10±0.7	0±10	0±7	N.D.	N.D.
Be	2.1	2.3	2.0	2.6	1	1	2.2±0.14	2.3±0.42	1±0	+0.1±0.44	1.2±0.14	N.D.	54±3
Cd	1.5	1.5	<0.5	<0.5	2	2	1.5±0.0	<0.5	2±0	>1.0	+.5±0	>67	N.D.
Cr	78	75	40	35	49	46	76±2.1	38±3.4	48±2.1	38±4.0	28±3.0	50±5	37±3
Cu	39	38	19	19	21	24	38±0.7	19±0	22±2.1	19±0.7	16±2.2	50±1	42±6
F	160	150	136	159	78	82	155±7.1	148±16.3	80±2.8	7±17.8	75±7.6	N.D.	48±3
Hg	0.05	0.06	-	-	-	-	0.06±0.014	- -	- -	- -	- -	-	-
Li	76	75	63	62	27	27	76±0.7	62±0.7	27±0	14±1.0	49±0.7	18±1	64±1
Mn	24	26	71	80	21	19	25±1.4	7.6±0.64	20±1.4	17.4±1.5	5±2.0	70±3	20±7
Ni	24	22	34	29	47	43	23±1.4	32±3.5	45±2.8	+9±3.8	+22±3.1	Gain	Gain
Pb	15	15	14	14	32	36	15±0	14±0	34±2.8	1±0	19±2.8	N.D.	Gain
Sb	7	<5	<5	<5	47	55	<6	<5	51±5.7	Ind	>45	Ind	Gain
Se	50	30	<5	<5	-	-	- -	- -	- -	- -	- -	-	-
Sn	5	<5	23	7	39	47	<5	15±11.3	43±5.7	>+10±11	>+38±6	Gain	Gain
V	62	46	68	70	54	50	54±11.3	69±1.4	52±2.8	+15±11.4	2±11.6	Gain	N.D.
Zn	36	33	11	12	21	24	34±2.1	12±1.4	22±2.1	22±2.5	12±3.0	65±5	35±7

Table F-8
TRACE ELEMENT ANALYSIS (PPM)
LUCAS MINE, MIDDLE KITTANNING SEAM, COLUMBIANA COUNTY, OHIO

Element	Individual Values						Average Values			PPM Change		% Loss	
	Raw Coal		Treated Coal				Raw Coal	Treated Coal		Meyers Process	Float-Sink	Meyers Process	Float-Sink
			Meyers Process		Float-Sink			Meyers Process	Float-Sink				
Ag	2.0	2.0	2.1	2.1	1	<1	2.0±0.0	2.1±0.0	<1	+0.1±0	>1	N.D.	>50
As	72	75	8.5	12.9	14	15	73.5±2.1	10.7±3.1	14±0.7	60±2.2	60±2.2	81±1	81±1
b	20	20	20	25	20	20	20±0	22±3.5	20±0	+2±3.5	0±0	N.D.	N.D.
Ce	3.6	3.9	3.6	3.7	3	3	3.8±0:21	3.6±0.07	3±0	0.2±0.22	0.8±0.2	N.D.	21±4
Cd	1.5	1.4	1.9	1.0	3	3	1.4±0.07	1.4±0.64	2±0.7	0.0±0.64	+0.6±0.7	N.D.	N.D.
Cr	53	52	26	28	28	26	52±0.7	27±1.4	27±1.4	25±1.6	25±1.6	48±3	48±3
Cu	13	13	16	17	8	7	13±0	16±0.7	8±0.7	+3±0.7	5±0.7	Gain	38±5
F	63	67	56	59	43	41	65±2.8	58±2.1	42±1.4	7±3.5	23±3.1	11±5	36±6
Hg	<0.1	<0.1	-	-	-	-	<.1	- -	- -	- -	- -	-	-
Li	8	8	5	6	4	5	8±0	6±0.7	4±0.7	2±0.7	4±0.7	25±9	50±9
Mn	17	13	7.7	5.4	10	9	15±2.8	6.6±1.63	10±0.7	8.4±3.2	5±2.9	56±14	33±13
Ni	35	35	33	21	30	20	35±0	27±8.5	25±7.1	8±8.5	10±7.1	N.D.	29±20
Pb	18	17	18	14	27	19	18±0.7	16±2.8	23±5.6	2±2.9	+5±5.6	N.D.	N.D.
Sb	<5	<5	6	6	7	5	<5	6±0	6±1.4	>5	>5	N.D.	N.D.
Sc	<5	16	2	3	-	-	8±8.0	2±1.4	- -	6±8.1	- -	75±30	-
Sn	5	16	<5	8	23	14	10±7.8	5±3.9	18±6.4	5±8.8	+8±10.1	N.D.	N.D.
V	14	9	19	15	5	12	12±3.5	17±2.8	10±5.0	+5±4.5	2±6.1	N.D.	N.D.
Zn	46	55	14	16	25	33	50±6.4	15±1.4	29±5.6	35±6.6	21±8.5	70±5	42±13

Table F-9

TRACE ELEMENT ANALYSIS (PPM)

BIRD NO. 3 MINE, LOWER KITTANNING SEAM, SOMERSET COUNTY, PENNSYLVANIA

Element	Individual Values						Average Values			PPM Change		% Loss	
	Raw Coal		Treated Coal				Raw Coal	Treated Coal		Meyers Process	Float-Sink	Meyers Process	Float-Sink
			Meyers Process		Float-Sink			Meyers Process	Float-Sink				
Ag	1.5	4.3	2.7	4.1	1	1	2.9±1.98	3.4±0.99	1±0	+0.5±2.2	1.9±1.98	N.D.	66±24
As	17.5	14.8	<.3	<.3	4	4	16±1.9	<0.3	4±0	>16±1.9	12±1.9	98±1	75±3
B	29.8	29.9	15.0	14.9	<5	<5	29.8±0.07	15.0±0.07	<5	14.8±0.10	27±.21	50±0.3	92±1
Be	3.5	3.6	2.6	2.6	4	4	3.6±0.07	2.6±0	4±0	1.0±.07	+0.4±.07	28±1	Gain
Cd	1.5	1.4	0.7	1.1	3	2	1.4±0.07	0.9±0.28	1.5±0.70	0.5±0.29	+0.1±.70	36±20	N.D.
Cr	152	146	58	64	56	56	149±4.2	61±4.2	56±0	88±5.9	93±4.2	59±3	62±1
Cu	23	29	12	10	16	15	26±4.2	11±1.4	16±0.7	15±4.4	10±4.3	58±9	38±10
F	115	95	111	119	48	49	105±14.1	115±5.6	48±0.7	+10±15.2	57±14.1	N.D.	54±6
Hg	0.10	0.10	-	-	-	-	0.10±0.0	- -	- -	- -	- -	-	-
Li	63	45	42	48	15	16	54±12.7	45±4.2	16±0.7	9±13.4	38±12.7	N.D.	70±7
Mn	46	44	8.3	10	22	19	45±1.4	9.2±1.2	20±2.1	36±1.8	25±2.5	80±3	56±5
Ni	35	36	24	45	55	34	36±0.7	34±14.8	44±14.9	2±14.8	+8±14.9	N.D.	N.D.
Pb	26	20	34	55	25	18	23±4.2	44±14.8	22±5.0	+21±15.4	1±6.5	Gain	N.D.
Sb	<5	<5	<10	14	50	39	<5	7	44±8.4	Ind	>+39±8	Ind	Gain
Se	<5	43	<5	8	-	-	- -	4	- -	- -	- -	-	-
Sn	25	5	23	16	50	23	15±14.1	20±5.0	36±19.1	+5±15.0	+26±24	N.D.	N.D.
V	74	46	60	70	35	33	60±19.8	65±7.1	34±1.4	+5±21.0	26±19.8	N.D.	43±19
Zn	90	70	8	10	24	23	80±14.1	9±1.4	24±0.7	71±14.2	56±14.1	89±3	70±5

Table F-10

TRACE ELEMENT ANALYSIS (PPM)

MEIGS MINE, CLARION 4A SEAM, MEIGS COUNTY, OHIO

Element	Individual Values						Average Values			PPM Change		% Loss	
	Raw Coal		Treated Coal				Raw Coal	Treated Coal		Meyers Process	Float-Sink	Meyers Process	Float-Sink
			Meyers Process		Float-Sink			Meyers Process	Float-Sink				
Ag	0.5	0.7	<1	<1	<1	<1	0.6±0.14	<1	<1	Ind	<1	Ind	Ind
As	2.7	2.5	-	-	-	-	2.6±0.14	-	-	-	-	-	-
B	120	110	100	100	100	90	115±7.1	100±0	98±3.5	15±7.1	17±7.9	13±5	15±6
Be	1.6	1.1	2.0	1.5	1	1	1.4±0.35	1.8±0.35	1±0	+0.4±.43	0.4±.35	N.D.	29±18
Cd	0.8	0.7	<0.5	<0.5	2	1	0.8±.07	<0.5	1.5±0.7	>0.3	+0.7±.70	>38	N.D.
Cr	99	100	49	47	50	51	100±0.7	48±1.4	50±0.7	52±1.6	50±1.0	52±1	50±1
Cu	24	22	13	14	12	10	23±1.4	14±0.7	11±0.7	9±1.6	12±1.6	39±5	52±4
F	220	224	197	223	71	65	222±2.8	210±18.4	68±4.2	12±18.6	154±5.0	N.D.	69±2
Hg	0.04	0.06	-	-	-	-	0.05±0.014	- -	- -	- -	- -	-	-
Li	22	23	21	22	-	-	22.5±0.71	21.5±0.71	11±0	1±1.0	12±.7	N.D.	51±2
Mn	40	49	14	18	23	19	44±6.4	16±2.8	21±2.8	28±7.0	23±7.0	64±8	52±9
Ni	20	23	22	24	26	21	22±2.1	23±1.4	24±3.5	+1±2.5	+2±4.0	N.D.	N.D.
Pb	12	13	2	11	22	23	12±0.7	6.5±6.4	22±0.7	5.5±6.44	+10±1.0	N.D.	Gain
Sb	16	<5	<5	<5	32	35	9±9.6	<5	34±2.8	N.D.	+25±10	N.D.	Gain
Se	58	68	<5	<5	-	-	63±7.1	<5	- -	- -	- -	-	-
Sn	5	25	32	23	17	20	15±14.1	28±6.4	18±2.1	+13±15.8	+3±14.2	N.D.	N.D.
V	55	46	41	42	45	45	50±6.4	42±0.7	45±0	8±6.4	5±6.4	16±10	N.D.
Zn	40	36	10	8	28	29	38±2.8	9±1.4	28±0.7	29±3.1	10±2.9	76±4	26±6

Table F-11

TRACE ELEMENT ANALYSIS (PPM)

KEN MINE, NO. 9 SEAM, OHIO COUNTY, (WEST) KENTUCKY

Element	Individual Values						Average Values			PPM Change		% Loss	
	Raw Coal		Treated Coal				Raw Coal	Treated Coal		Meyers Process	Float-Sink	Meyers Process	Float-Sink
			Meyers Process		Float-Sink			Meyers Process	Float-Sink				
Ag	1.7	1.2	1	2	<1	<1	1.4±0.35	1.5±0.71	<1	+0.1±0.79	>0.4±.35	N.D.	28±17
As	6.5	6.5	0.5	0.5	1	1	6.5±0	0.5±0	1±0	6±0	5.5±0	92±0	85±0
B	60	60	60	60	55	50	60±0	52±3.5	52±3.5	8±3.5	8±3.5	13±6	13±6
Be	2.0	2.0	3	3	1	1	2.0±0	3±0	1±0	+1±0	1±0	Gain	50±0
Cd	2.3	1.1	1	<.5	2	3	1.7±0.9	2.5±0.71	2±0.7	+0.8±1.1	+0.3±1.1	N.D.	N.D.
Cr	75	78	37	35	40	40	76±2.1	36±1.4	40±0	40±2.5	36±2.1	53±2	47±2
Cu	17	16	12	12	9	8	16±0.71	8±0.7	8±0.7	8±1.4	8±1.4	50±5	50±5
F	126	123	-	87	59	49	124±2.1	54±7.1	87	70±7.4	37±7.4	56±6	30±6
Hg	<0.2	<0.2	-	-	-	-	<0.2	- -	- -	- -	- -	-	-
Li	9	9	10	10	5	6	9±0	10±0	6±0.7	+1±0	3±0.7	N.D.	33±8
Mn	64	56	5	5	33	34	60±5.7	5±0	34±0.7	55±5.7	26±5.7	92±1	43±6
Ni	35	26	16	17	27	25	30±6.4	16±0.71	26±1.4	14±6.4	4±6.6	47±12	N.D.
Pb	19	13	4	4	23	19	16±4.2	4±0	21±2.8	12±4.2	+5±5.0	>5±7	N.D.
Sb	30	17	29	40	12	8	24±9.2	34±7.8	10±3.5	+10±12	14±9.8	N.D.	58±22
Se	<5	<5	-	-	-	-	1±1.4	- -	- -	- -	- -	-	-
Sn	<5	21	4	4	43	25	12±13.1	4±0	34±12.7	8±13.1	+22±18	67±36	Gain
V	32	38	22	19	31	26	35±4.2	20±2.1	28±3.5	15±4.7	7±5.5	43±9	20±14
Zn	40	39	19	15	35	36	40±0.7	17±2.8	36±0.7	23±2.9	4±1.0	58±7	10±3

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